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The British quarterly scientific journal ENDEAVOUR was first published, by Imperial Chemical Industries Limited, in January 1942. Its purpose is to provide scientists, especially those overseas, with news of the progress of the sciences. While emphasis is laid upon British work, narrow insularity is avoided by publishing a number of articles from overseas contributors and by impartial reference to the world's scientific literature. To make the journal truly international in character it is published in five separate editions—English, French, German, Italian, and Spanish.

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The drawing on the cover is of the bark Endeavour, which, commanded by Captain James Cook and carrying a number of scientific workers, was sent out by the British Admiralty in 1768 to chart the South Pacific Ocean and observe the transit of Venus

ENDEAVOUR

A quarterly review designed to record the
progress of the sciences in the service
of mankind

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Benjamin Franklin

Benjamin Franklin, the two hundred and fiftieth anniversary of whose birth falls in January 1956, was a man equally effective and at ease when investigating the behaviour of concordant inanimate nature and when concerned with the conduct of discordant humanity. In all his undertakings he showed a supreme ability to distinguish the essential from the inessential, the significant from the obvious but trivial. With this quality went his clear-headed power of first determining what ought to be done and then of finding the appropriate means for doing it. A general perspicacity and shrewdness characterized his conduct as a business man and played some part in his excellence as a writer. These powers were, of course, supplemented by many other virtues and by certain other human characteristics.

Franklin is most widely known as the man who established the electrical nature of lightning and designed the first effective lightning conductor, and this is certainly one, but by no means the only one, of his great services to science. That lightning and the electric spark produced by the frictional machines of the time had something in common had been casually conjectured before, but it was Franklin who first went into the matter systematically, giving twelve particulars in which 'electrical fluid' resembled lightning. He also carried out a series of experiments on the effect of sharp points, which were in effect earthed, on discharging electrified bodies in whose neighbourhood they were placed. This led him to propose the form of lightning rod with which his name is so intimately associated—'Would not,' he asks, 'these pointed rods probably draw the electrical fire silently out of a cloud before it came nigh enough to strike, and thereby secure us from that most sudden and terrible mischief?' He suggested an experiment in which a man, standing on an insulating block in a sentry box on a high building, should draw sparks from thunder clouds by means of a pointed rod, an experiment which, following his proposal, was successfully carried out in France.

The experiment with the kite, which so struck the popular imagination that it has ever since been the one achievement generally associated with his name, was done later in Philadelphia. The kite was flown on a twine which, when wetted by the rain, became a conductor—fortunately not a good one—insulated from the hand by a silk ribbon. With his knuckles Franklin drew sparks

from a key attached to the twine. The experiment is not always described correctly and was, as it turned out, only a confirmation of what had already been established, following Franklin's reasoning and at his prompting. Franklin, however, has little to complain of in being represented by it in the popular mind when it is considered that Newton is represented by a falling apple.

Franklin's careful studies in static electricity, a very difficult subject for conclusive experiment, on account of the apparently capricious behaviour of the rubbed bodies, led him to enunciate quite clearly that the effect of the friction was to separate two kinds of charges which cancelled one another if brought together. To explain this he put forward his one-fluid theory. According to this, the one electrified body has an excess of fluid and its partner an equal defect, which led him to introduce the terms positive and negative electricity, as used today. There is not, in principle, any great difference between the one-fluid and the two-fluid theory—a negative wealth may equally well be called a debt, something of its own kind—but Franklin's treatment very much clarified the whole subject. He has, in fact, been called the founder of electrical science.

In this connection, the importance of his work on the condenser is often overlooked. The discovery of the Leyden jar, when Franklin was about 40, created a sensation, largely by reason of its power of giving severe physical shocks. Franklin showed the equal and opposite nature of the charges on the two coatings, or, in his own words, that 'the Leyden bottle has no more electrical fire in it when electrified, than before', and further demonstrated that the energy of the bottle resided in the glass. In the course of his work he made the more convenient plane condenser, consisting of a sheet of window glass between thin plates of lead, sometimes known as 'Franklin's pane'. Of such plane condensers he made what he called an electrical battery, sometimes referred to as an electric cascade. The system of charging with one set of connections and discharging with another set is a foreshadowing of Cockcroft and Walton's method of producing high potentials.

Passing reference may be made to work of some importance that he carried out on heat. Franklin was eminently a practical man and, like his countryman Rumford, effected great improvements in the domestic stove, concerning which, as

it existed before, he wrote: 'In short, many of the diseases proceeding from colds . . . may be ascribed to strong-drawing chimneys, whereby, in severe weather, a man is scorched before, while he's froze behind.' He was the first inventor of bifocal spectacles, improved the musical glasses in an instrument that he called the armonica, designed new forms of various domestic devices, and so on. He, very naturally, prided himself upon the utility of the lightning conductor, and, with this probably in mind, produced one of his epigrammatic passages: 'Nor is it of much importance to us to know the manner in which nature executes her laws: 'tis enough if we know the laws themselves. 'Tis of real use to know that china left in the air unsupported will fall and break, but how it comes to fall, and why it breaks, are matters of speculation. 'Tis a pleasure indeed to know them, but we can preserve our china without it.' His fundamental researches on the behaviour of electric charges clearly show that the pursuit of pure knowledge was for him a pleasure.

Franklin's scientific work, to which, when he sold his printing business for a large sum in 1748, he looked forward to devoting much of his time, actually occupied but a small part of his life. Before the days of his scientific fame he became widely known by his publication 'Poor Richard's Almanack', in which he used to intersperse dry apothegms, many of which have become part of the proverbial sayings in the English language. On account of his personal popularity, his wisdom, his vigour, and his uncommon common sense he was called on to take a leading part in the public life of what were then the American colonies. When, in 1757, a delegate was required to represent the discontents of these colonies, and their causes, Franklin was chosen for the mission. He spent five years in England on this occasion and returned again in 1764 on a further mission of the same nature, which only terminated when, in 1775, there was no prospect of a satisfactory outcome. This is clearly no place for an estimate, however short, of his political activities, but it is agreed that they showed him as upright, incisive yet urbane, and wise, a sage councillor and a farsighted negotiator. His effort throughout, to which he was moved both by his heart and by his head, was to maintain the union between England and America, as senior and junior partner joined by the honorable regard of each for the rights and

interests of the other. His endeavours to effect this object failed, but by no fault of his own. Where Franklin and Chatham were unsuccessful, it is doubtful if any two other men could have succeeded. Franklin's subsequent sojourn in France likewise showed him as a man of learning and a man of the world, welcomed in every rank of society.

It is pleasant to record that Franklin's relations with all the best elements of English life were throughout most cordial. He visited London as an unknown youth and then conceived a warm regard for English ways. His electrical researches were first published in England by the agency of an English friend, and before his next visit he received for them the Copley medal of the Royal Society. When he then came as the official representative of the colonies and as a man famous for his scientific work he at once entered on terms of friendship with outstanding figures of English scientific, social, and political life. He was elected a Fellow of the Royal Society in 1756, and frequently served on the Council of that body. His relations with the then recently founded Royal Society of Arts were equally cordial and intimate. His system of lightning conductors was widely adopted on public buildings and defended by leaders of English science when attacked by a rival after war had broken out. Franklin was, of course, a signatory of the Declaration of Independence, but throughout the period of hostilities his general goodwill remained; he arranged, for instance, for Captain Cook not to be molested by American cruisers, should they meet him on his voyages of exploration. As soon as the war was over, Franklin, who expressed heartfelt satisfaction at its end, received with the approval of George III a copy of Cook's 'Voyages' and a very cordial and conciliatory letter from Sir Joseph Banks, President of the Royal Society, accompanying the gift of a gold medal that had been struck in Cook's honour.

Franklin was a comprehensive and clear-headed genius who achieved outstanding things in pure and applied science, and who, as a man of business, a man of affairs, and a statesman showed the greatest honesty, wisdom, and courage. He was an admirable writer and both in domestic and in national affairs a sage counsellor and a firm leader. He was a wholehearted and practical promotor of international confidence and co-operation. One such is worth many conferences.

The organization within nerve cells

J. Z. YOUNG

In the cytoplasm of all cells there occur several types of particles that are complex molecular aggregates surrounded by membranes. The functions of these are far from clear and it is here suggested that these particles serve as signals by which the nucleus controls the complex operations of the cell. The argument is illustrated by particular reference to nerve cells; these, being large, are especially suitable for study of this intracellular communication system.

Little progress has been made in describing the supramolecular organization within cells, although biochemists from Gowland Hopkins onwards have realised that such a study is necessary [29]. Even the aims and principles appropriate to an inquiry into cellular organization are still not clear, nor what units it should deal with. It has often been suggested that the organization may depend upon a cytoskeleton, presumably of protein, but while this may indeed exist in some cells a more profitable approach is to consider that the organization is not static and that there is constant interchange and communication between parts of the cell. The approach to the problem of intracellular organization suggested here takes account of three considerations: (1) that cell metabolism proceeds in such a manner that life maintains a steady state in spite of external changes; (2) that this circumstance implies a two-way communication between the cell surface and some central system within, presumably, the nucleus; and (3) that much of the material of cells is divided into particles. The characteristic properties of organisms are the result of the fact that they contain certain special groupings of molecules, acquired as a result of past history. No methods are yet available for showing the relations between the many rapidly changing processes in different parts of cells, and this very long sequence of past events. Nevertheless, it is not too early to begin thinking about the problem. Cytology cannot be content to go on indefinitely finding new visible parts of the cell: nor can it be satisfied even by identifying these parts by histochemical methods. What it needs is to discover methods that will describe the organization of cellular events and allow this organization to be compared under different conditions and in various types of cell.

Materials are continually pouring into and out of the cell, and to elucidate the probable course of metabolism of each type of molecule as it enters is

one way of discovering the nature of the system as a whole. Life continues because certain sets of substances have been selected and grouped together during the past history of the system. These sets have provided reactions adequate to maintain the steady state in the conditions that have been encountered in the past. They have been built up by a process of trial and error among an enormous number of possible combinations, any that are unstable being rejected. The process is successful in providing systems that are stable under various and varying conditions because of the capacity of carbon to build a vast number of compounds that differ slightly from each other, among which suitable combinations may be selected.

THE CELL AS A COMMUNICATION SYSTEM

The immediate problem is to find ways of describing the combinations and of showing how they direct the course of metabolism. The method of selection of the particular sets of molecules effective in any organism at any time is in the last resort that of natural selection: it seems likely, therefore, that some form of stochastic treatment may be useful for describing cellular organization.

It is not unrealistic to compare a cell or an organism and its surroundings with a communication channel. The value of the comparison derives from the fact that both situations deal with the limitations upon future behaviour imposed by sets of combinations that have been selected in the past. Communication theory deals with the way in which 'decisions' are influenced by 'information'. The information is transmitted by choosing from a prearranged code the combination of symbols that is appropriate to a particular environmental situation. After suitable transmission this information controls the behaviour of the receiver in such a way that it makes a correct adjustment to the situation. If the information is sent from a peripheral source to some controlling centre, the

response of the latter may consist in the transmission of instructions to the periphery, according to the principle of operations embodied in the control centre.

The concept of 'receptors' at the cell surface is already quite familiar to biochemists and pharmacologists. Events occurring in the immediate neighbourhood of an organism or cell act as selectors among a limited set of chemical operations that are possible near the surface. This is comparable to selection of certain words from a language to form a message. The possible cell reactions have been preselected, like the words, to suit certain likely external events. The changes near the surface of the cell influence reactions further in; these follow rules of which we are almost wholly ignorant, but presumably they too depend on the previously selected arrangements. Thus we can consider that 'information' is transmitted inwards and ultimately reaches the nucleus, which contains the ultimate controlling agency and is the most constant component in the cell.

The mean amount of deoxyribose polynucleotides (DNA) in the nuclei of all the somatic tissues of any one species is the same (table I). The amount in the sperm nuclei is half that in the somatic nuclei. In a tissue such as rat liver, where the content is high, some of the cells contain more than one chromosome complement [13].

TABLE I
Mean content of DNA per cell ($10^{-12}g$)

	Rat	Fowl	Ox	Frog	Toad	Carp
Liver	9.4	2.6	6.4	15.7	—	3.3
Kidney	6.7	2.3	—	—	—	—
Spleen	6.5	2.6	—	—	—	—
Lung	6.7	—	—	—	—	—
Leucocytes ..	6.6	—	—	—	—	—
Erythrocytes ..	—	2.6	—	15.0	7.3	3.5
Heart	6.5	2.5	—	—	—	—
Pancreas	7.3	2.7	—	—	—	—
Brain	—	2.3	—	—	—	—
Muscle	—	2.5	—	—	—	—
Sperm	—	1.3	2.8	—	3.7	1.6

The relative constancy of this component in the cell is of the greatest interest, since we know from many facts that the nucleus provides the central control system that ensures the constancy of each type of living organism. Nuclear behaviour during cell division shows elaborate mechanisms by which the constancy is preserved in copying, the material being arranged in distinct units, the genes, regu-

larly aligned on discrete chromosomes. During the formation of the germ cells there is a meticulous arrangement for halving this material and ensuring that the next generation starts with the standard amount of nuclear material, with one copy of each part of it derived from each parent. The male contribution consists of little else besides these nucleoproteins. Thus the nucleus provides the instructions that ultimately control the metabolism of every cell.

The operation of the control system must consist essentially in sending outwards into the cell communications that constitute the instructions. According to these instructions, 'decisions' are made between one course of metabolism and another. From the environment, meanwhile, information is continually transmitted inwards through the cytoplasm, ultimately presumably influencing the instructions that are sent out by the control system of the nucleus. Except in rare cases (mutations) this information does not alter the basic properties of the control system itself, which remains as the determinant of the characteristic behaviour of each cell of the species.

THE SIGNIFICANCE OF PARTICLES IN THE CELL

It is thus easy to see that a general comparison can be made between a cell and a two-way communication system. If this was merely an entertaining *façon de parler* it would be of little value, but there are indications that it could be made more precise and may provide a method by which we could describe the elusive organization of the cell. One of the most striking facts of cytology is that much of the cellular material is aggregated into particles of various types, which are found, varying somewhat in detail, in all animal and plant cells. The chromosomes, with their subdivision into chromomeres and bands, are the most familiar example. In the cytoplasm there are bodies of various sorts, mitochondria, lipochondria (Golgi substances), endoplasmic reticulum, and microsomes, which will presently be described. Cytologists have long recognized that these bodies are not composed of a single chemical species but are quite complicated aggregates. For example, mitochondria are complex structures containing proteins and phosphatides and are the bearers of a large range of enzymes [33].

Perhaps the fact that these complex aggregates are arranged as discrete bodies is one of the most significant things about them as fundamental components of life-systems that maintain stable states.

Communication theorists are familiar with the fact that if a message is to be transmitted along a channel and remain stable it must be recorded in the form of discontinuous units [24, 34]. Any attempt to transmit a representation of a complicated pattern of events by a continuous process of making exact copies is bound to fail because of the errors of copying due to noise, which are cumulative. The solution that is adopted for communication is to code the message into discrete symbols, each of which is transmitted and copied completely or not at all. Words are of this nature, as of course are the dots and dashes of the morse code or the nerve impulses that constitute the code of the nervous system.

It may be that we see here the significance of the fact that cells contain discrete granular aggregates. Each such cell particle may be compared to a signal. It has a definite significance as the bearer of what we may call conventional meaning, in the sense that it has been built up in the past by selection of materials appropriate to produce a particular effect under suitable conditions. Each granule or particle, like a word, is built up until it is complete and then operates as a unit, able to elicit a certain metabolic response according to the conditions that it meets. Being composed of such units the cell is able to transmit a stable pattern of behaviour.

ADVANTAGES OF MICROSCOPY FOR THE STUDY OF CELL ORGANIZATION

If this approach has any value there is a worthwhile task for cytologists in studying these discrete components of the cells, their mode of formation, frequency, and distribution. Unfortunately suitable quantitative data are as yet few, and they will have to be collected with these specific objectives in mind. The light- and electron-microscopes are fortunately very suitable instruments for this purpose, though they suffer from some severe limitations. With them it is difficult to identify the chemical composition of the particles, though histochemistry has made great advances in this respect. The great advantage of microscopes is that they provide a high degree of resolution in space. Cellular particles range from a few angstroms in diameter upwards, and their relations and distribution in the cell can hardly be studied by methods of isolation, valuable though these methods may be for other purposes.

The large amount of water in living tissues makes microscopy difficult, since it must be removed to obtain high resolution. This limitation

has deterred many who hanker after 'study of the living cell'. However, if the procedures of preparation are properly arranged this need not introduce any unusual difficulty of principle. Perhaps the most severe difficulty of work at high optical resolution is that the cell can be studied only at one instant. This poor resolution in time can be avoided only by laborious experiments in which series of samples are fixed.

NEURONS AS MATERIALS FOR THE STUDY OF TRANSMISSION WITHIN CELLS

Neurons are suitable in many ways for the study of the organization and communication within cells. They are large and internally differentiated into distinct parts (figure 2). It is easy to show that all parts of a neuron are under the control of the nucleus, lying in the nerve-cell body. Any part that is cut off from the cell body begins to show degenerative changes within a few hours. Throughout life, therefore, something that prevents degeneration must be transmitted to the distant parts of the cell. There is also transmission in the reverse direction, for after a nerve fibre has been severed changes occur within the cell body, which begins an active process of protein synthesis, allowing regeneration of the nerve fibre (p. 8). Indeed, the synthetic system within the cell body changes its operations to suit the functional activity that has occurred and the supply of raw materials provided. Further evidence of communication between different parts of a neuron is that when a young nerve fibre makes connection with a muscle the whole fibre is stimulated to grow [1]. The problem is to identify the transmission system involved and to discover whether it operates by means of any discrete units or signals.

THE NUCLEUS

The nucleus contains a number of highly specific particles, the genes, but in adult neurons no visible sign of these can be detected with either the light- or the electron-microscope. The nucleic acids in the nucleus give it the characteristic property of staining with basic dyes (figures 3-6, 27, and 29). The stain is not uniform, and various types of relatively large bodies are found. In neurons of cephalopod molluscs such as squid, cuttlefish, or octopus there is usually a deeply basophil nucleolus and one or more less basophil bodies, the plasmosomes. There are also many smaller basophil granules, and a nuclear sap that is unresolved by the light microscope. The nucleolus is a constituent of nearly all nuclei.

Specific staining methods, and the fact that it absorbs ultra-violet light at 2750 Å, show that it contains a large amount of ribosepolynucleotides (RNA). The nucleoli become enlarged in any cell that is undergoing rapid protein synthesis, for example in nerve cells that are regenerating after their nerve fibre has been severed. It is suggested that the nucleolus is the seat of collection of RNA during its synthesis from, or under the control of, DNA [7, 12].

In the sea hare, *Aplysia*, the nucleolus contains one or more bodies with a refractive index very different from that of the rest. These can be seen in both living and fixed cells (figures 7-10 and 12), but their nature is not known. The details of the organization of the nucleolus remain obscure. In electron micrographs it may appear to contain numerous spherical areas of lesser density (figure 1), but these may be artifacts, and the nucleolus has been reported to contain masses of filaments, sometimes with granules attached [5].

Although in most adult nuclei the chromosomes are not visible, the 'nuclear sap' is certainly not a homogeneous material. In mammalian neurons there are electron-opaque bodies of various sizes. Some of these are finely granular and may show signs of regular arrangements of the granules. In addition the nuclear sap contains a number of electron-opaque spheres of diameter up to 200 mμ, which may be the precursors of lipochondria (p. 10). Mention must also be made of the nucleolar satellite, a basophil body containing DNA, which is larger in the neurons of female than male mammals and therefore presumably represents the sex chromatin derived from the X chromosomes [25].

The boundary between nucleus and cytoplasm is marked by a membrane, up to 40 mμ thick, which must be the seat of important processes regulating the passage of materials inwards and outwards. This is seen in a living cell in figure 13 and in electron micrographs in figures 1 and 2. The details of its composition are still not known. It contains two dense layers separated by a lighter one up to 20 mμ in thickness. It is not equally dense at all points, and the two layers may be joined at intervals by what may be holes or channels of different permeability (figure 2) [27, 18]. There is little doubt that quite large particles pass through the membrane, but there is little evidence as to whether they go inwards as well as outwards or what controls their formation. The main cytoplasmic components to be described below—mitochondria, ergastoplasm, and lipochondria—

may all occur close to the outer surface of the nuclear membrane (figure 1), and it would be extremely interesting to know whether they are formed there or pass through the membrane.

Our knowledge of visible nuclear structure at present provides hints, but few facts, as to the way it receives information from the cytoplasm and transmits instructions back to it. The most definite clue is that the production of ribonucleotides is increased in the nucleolus whenever a cell is stimulated to protein synthesis. The presumption is that the RNA passes outwards through the nuclear membrane to form the basis of the synthetic processes in the cytoplasm. What we need to know is whether this transmission takes place as a continuous flow or in the form of discrete particles. During the phase of regeneration of a nerve cell after severance of its axon, new RNA probably appears at the nuclear surface (see figure 6). The nuclear membrane then shows folds and thickening [18], and vesicles may be seen actually within these folds and are perhaps formed there. Masses of electron-opaque granules have been seen on both sides of the nuclear membrane, suggesting that transfer takes place in the form of discrete packets or granules. Opinions as to the nature of these bodies formed at the nuclear surface vary; they may be ergastoplasm [14], defined later, or mitochondria [18, 9]. There are also suggestions that lipochondria may be formed at the nuclear surface (see below). There are, therefore, indications that communication between nucleus and cytoplasm is in the form of signals consisting of organized aggregates.

CYTOPLASMIC NUCLEIC ACIDS

It is characteristic of nerve cells that their cytoplasm contains large masses of basophil material called, after its discoverer, the Nissl substance. It is now known that the material includes ribonucleotides and that these are arranged in units of specific structure, to which the name endoplasmic reticulum or ergastoplasm has been given [27].

The Nissl substance is seen with the light-microscope as masses of deeply basophil material, often divided into clumps or bodies by clearer spaces (figures 3-6 and 41). Electron microscopy shows that the Nissl bodies are aggregates of masses of narrow tubes, which are often, but not always, covered with fine granules (figure 1b). The tubes may take different forms as flattened cisternae, tubules, and vesicles, making an elaborate branching and intercommunicating system. The limiting

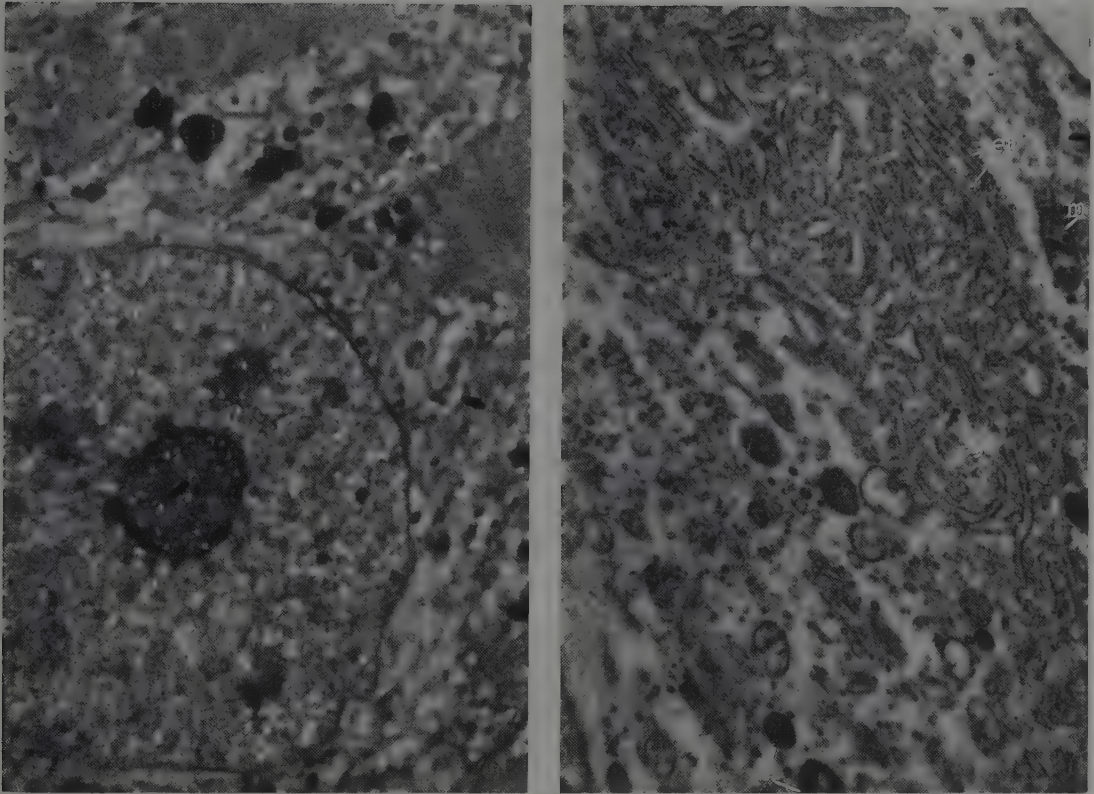


FIGURE 1 — (a) (left) Low-power electron micrograph of nucleus and nearby regions of a nerve cell of the spinal cord of the rabbit. Fixed osmium tetroxide and photographed without removal of the embedding plastic. There is a large nucleolus with chromatin masses (possibly DNA) near it. The nuclear sap contains many granules, including relatively large opaque spheres (possibly lipochondria precursors). Outside the nuclear membrane are lipochondria, mitochondria, and Nissl substance, the last not showing its internal organization ($\times 10\ 000$). (b) (right) Portion of cytoplasm of a cat's neuron, showing vesicles of endoplasmic reticulum (er) with granules (microsomes) attached (g). The mitochondria (m) show internal division by septae; l, lipochondria. (From Palay and Palade [27].) ($\times 24\ 000$)

membranes are 6–7 μ thick and the lumina vary from 30 to 50 μ , with wider dilatations. The granules attached to these tubules are 10–30 μ in diameter and are commonly arranged in clusters or rosettes of five or seven together, but also occur singly or in rows. The granules are comparable to the microsomes, basophil particles that can be isolated from liver and other tissues by centrifugation [10]. In liver cells this fraction has been shown to contain proteolytic enzymes.

Proceeding away from the nucleus, the Nissl granules become in general smaller and formed of less and less regularly arranged reticulum. Approaching the outside of the cell or a dendrite, the reticulum becomes broken up into smaller and smaller components, and in the peripheral parts of the cell it appears as a very loose network or as separate tubules, with or without attached granules.

In the preparations shown in figure 41 removal of the plastic has distorted the individual elements of the reticulum so that they appear as threads with granules attached.

The distribution of this material through the cell can be approximately followed by light-microscopy by studying the basophilia. The cytoplasm of the cell body stains intensely with basic dyes, showing the Nissl granules. Proceeding away from the cell body along either axons or dendrites the intensity of staining diminishes, rapidly at first, later more slowly. No measures of this change are available, but the difference between material close to and away from the cell body is shown clearly where the distal end of one cell comes into close contact with the more proximal part of another one at a synapse (figures 14 and 36).

All this evidence is compatible with the suggestion that the endoplasmic reticulum and its ribonucleic acids are concerned in the synthesis of material, perhaps protein, under the influence of the nucleus. Specific ribonucleoproteins may be produced within the cell body and then passed down the processes of the nerve to conduct further synthesis there. A nerve fibre whose axon is 10 μ in diameter may be a metre or more long, and it is difficult to imagine how transport could be effected along such a very narrow channel. Nevertheless there is reason to think that it does take place. Active movement along axons is readily seen in tissue culture, and there is a considerable body of evidence suggesting transport away from the cell body along nerve fibres [37, 41]. Every part of the nerve cell depends upon the cell body, and any part that is cut off begins to degenerate and breaks up within a few days. There must therefore be some form of transmission along the nerve fibre responsible for the maintenance of the organization. Nerve fibres very readily assume an unduloid outline (figure 16), and it has been suggested that the material of which they are composed has liquid properties and tends to break up as a result of surface tension effects [41]. Pressure within the fibre would prevent this break-up, and there is probably also a continual transfer of material along the fibre. If nerve cells are cut out and left completely isolated from the body, signs of the movement of the Nissl substance from the cell body to the axon can sometimes be seen in the course of a few hours (figure 17).

The cytoplasmic nucleotides readily change their activity in response to changes in the nerve fibre. If the axon is severed the Nissl substance first reduces in amount (figure 5, chromatolysis) and is then re-formed, at or near the surface of the nucleus (figure 6). Moreover, if a nerve cell is made continuously active for some time the cytoplasmic ribonucleotides increase [20]. There must therefore be some agency by which transmission from peripheral parts of the cell to the centre takes place.

THE LIPOCHONDRIA

The system known as the Golgi apparatus contains various distinct substances. This can be clearly seen in the neurons of molluscs, which will be considered here [40]. The Golgi bodies consist primarily of spheres, the lipochondria [3], which contain phosphatide and other material. They are coloured yellow in some cells (see later) and

stain intravitaly with neutral red, methylene blue, and other dyes. Associated with these bodies are other substances, and the whole system may adopt net-like or other appearances after fixation, especially since the lipochondria are very sensitive to changes in osmotic pressure (see below).

If thin slices of a ganglion of an octopus or cuttlefish are examined in sea water there are seen to be numerous colourless or faintly yellow spheres in the region around the nucleus. These bodies can be stained with neutral red (figure 18), a dye that sometimes colours structures pre-formed in the cells, though it may also set up reactions that lead to the production of bodies that were not previously present. In these nerve cells of cephalopods it is possible to see the unstained bodies and to watch the appearance of colour in them when a dilute solution of neutral red is run under the coverslip. The stained bodies show interesting changes as the tonicity of the medium is varied. In hypotonic solutions they swell and in hypertonic solutions they shrink. The process is reversible, and a single droplet can be watched passing through several complete cycles (figures 19-25). When shrunk the surface often becomes crumpled (figures 22 and 24) and the droplet may assume various forms, some of them suggesting that the plasmolysis has led to the drawing away of an inner compartment of the drop, leaving the original outline faintly apparent (figures 20 and 24). Such crescent-like appearances are difficult to interpret except on the assumption that the droplet is covered by two membranes which can be separated [40, 42]. There is no evidence from electron microscopy as to whether double layers exist around these bodies in molluscan nerve cells. Other cell constituents have been shown to carry double membranes, in particular the mitochondria [11, 26], which have also been shown to swell and shrink with changes in the tonicity of the medium [10, 35, 32].

The properties of such intracellular membranes are obviously of outstanding interest, since they represent sites at which metabolic processes are controlled. It has often been assumed that the main regulatory surfaces of the cell are the outer cell membrane and the nuclear membrane. The situation is much more complicated if we have to consider the presence of several other types of specific surface, such as those of the endoplasmic reticulum, mitochondria, and lipochondria. For example, many calculations of the position of free water in the body have assumed that osmotic interchanges take place at the cell surface. The

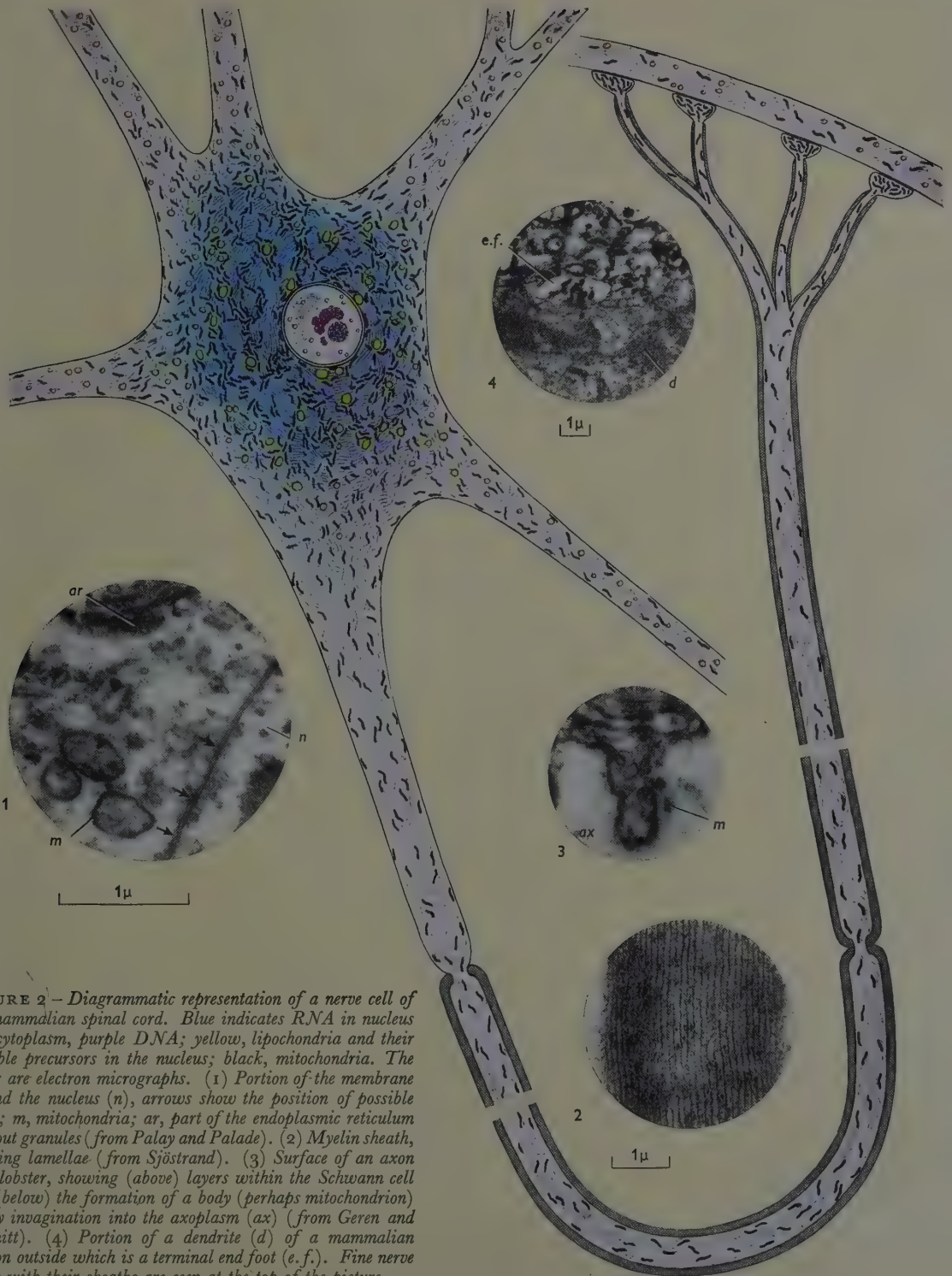


FIGURE 2 - Diagrammatic representation of a nerve cell of the mammalian spinal cord. Blue indicates RNA in nucleus and cytoplasm, purple DNA; yellow, lipochondria and their possible precursors in the nucleus; black, mitochondria. The insets are electron micrographs. (1) Portion of the membrane around the nucleus (n), arrows show the position of possible pores; m, mitochondria; ar, part of the endoplasmic reticulum without granules (from Palay and Palade). (2) Myelin sheath, showing lamellae (from Sjöstrand). (3) Surface of an axon of a lobster, showing (above) layers within the Schwann cell and (below) the formation of a body (perhaps mitochondrion) m, by invagination into the axoplasm (ax) (from Geren and Schmitt). (4) Portion of a dendrite (d) of a mammalian neuron outside which is a terminal end foot (e.f.). Fine nerve fibres with their sheaths are seen at the top of the picture.

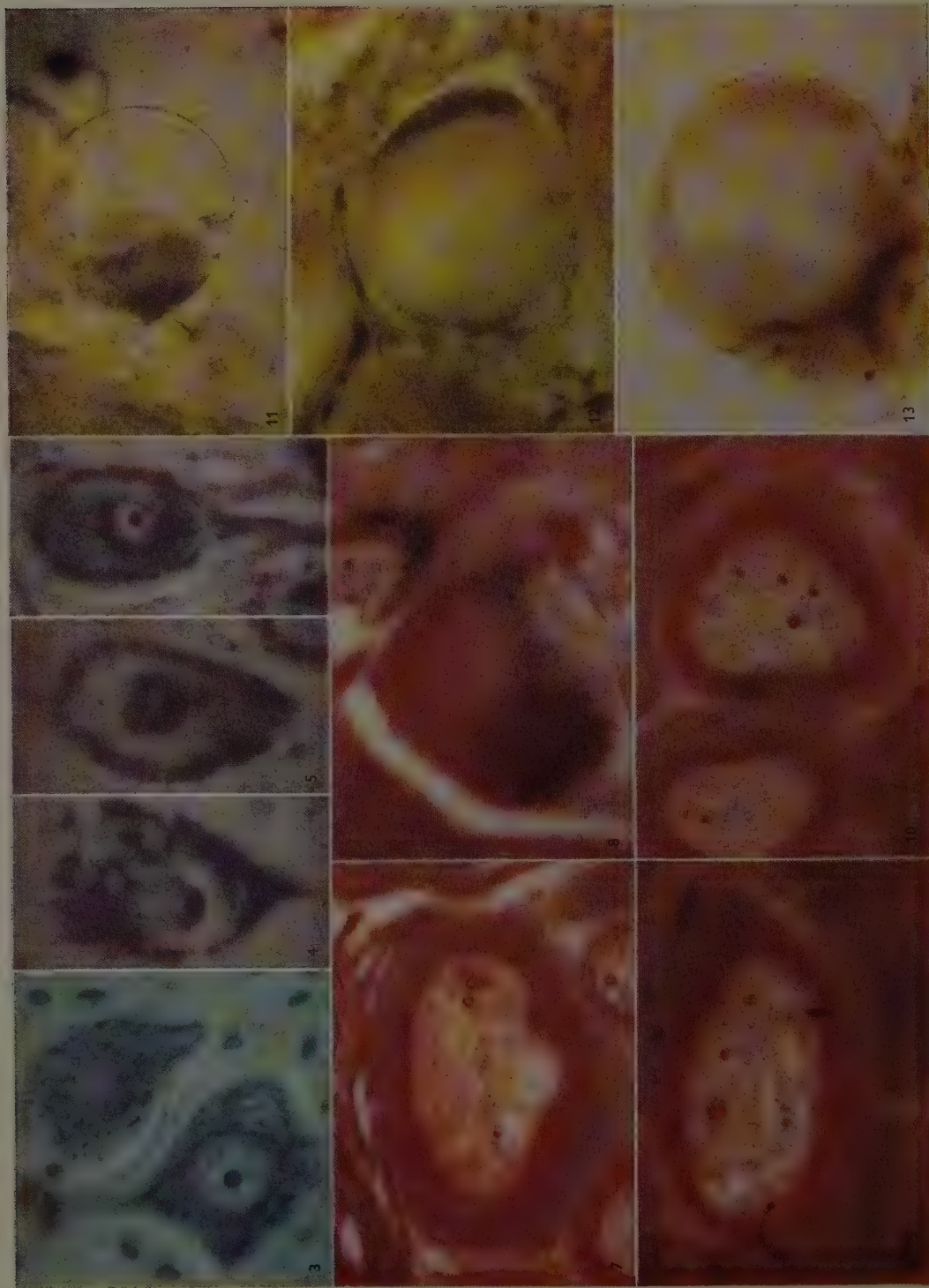


FIGURE 3 - Cells of spinal cord of cat. This and figures 4-6 were fixed in Carnoy's fluid and stained toluidin blue, showing the basophil material (mainly nucleotides) in nucleus and cytoplasm. FIGURE 4 - Normal nerve cell of octopus. FIGURE 5 - Octopus nerve cell whose axon was cut seven days previously, showing disappearance of cytoplasmic nucleotides. FIGURE 6 - Similar cell 17 days after axon was cut. The nucleotides are reappearing in the cytoplasm, and are especially abundant around the nucleus. FIGURES 7-10 - Nerve cells of the sea hare (Aplysia); fixed in a chrome-osmium acetic mixture and stained with safranin. The basophil nucleoli contain unstained refringent bodies. The cytoplasmic nucleotides appear as a reddish ring around the nucleus. The lipochondria are stained black by the osmium (especially in figure 8). FIGURES 11-13 - Living nerve cells of the sea hare, examined in sea water. The large nucleus contains fine granules, and in figure 12 a nucleolus with refringent centre is seen. In the cytoplasm are masses of lipochondria containing yellow pigment.



FIGURE 14 - Section of a giant synaptic junction in the squid. The incoming (presynaptic) fibre contains so little basophil material that it is hardly stained, whereas the post-synaptic axoplasm is dark. The contact between the two is made by a tongue of post-synaptic protoplasm, proceeding up from the main body of the giant fibre, seen at the left of the picture. Red synaptic granules are seen near the surface of contact. Fixed with picric acid in sea water; stained Masson's trichrome stain. FIGURE 15 - Section across a dendrite of a giant cell of the squid. The presynaptic fibres end in knobs around the dendrite, and red synaptic granules are present. Preparation as figure 14. FIGURE 16 - Portion of a normal rabbit's nerve, stained Bodian's fluid; stained Bodian's fluid. FIGURE 17 - Nerve cell of cuttlefish (Sepia), seen after isolation in sea water and staining with neutral red. The cytoplasmic nucleolus has been moved down the axon. FIGURE 18 - Nerve cell of cuttlefish (Sepia), seen after isolation in sea water and staining with neutral red. The cytoplasmic nucleolus has been moved down the axon. FIGURE 19 - Single lipochondria of Sepia stained with neutral red. In 21 sea water diluted to half normal tonicity has been added. FIGURES 22-25 - Similar cells from a ganglion that was taken out of the body and kept for 24 hours before fixation in alcohol and staining with toluidin blue. FIGURE 26 - Neurons of spinal cord of rabbit stained with silver by the da Fano method for the 'Golgi apparatus' and counterstained with neutral red and light green. The lipochondria appear as dark spheres, which may run together to form networks. FIGURE 27 - Rabbit spinal cord neurons. Stained by the da Fano, counterstained Azan method; nucleolides red or brownish. FIGURE 28 - Octopus neurons stained with da Fano's silver and toluidin blue. The lipochondria appear as distorted golden spheres, sometimes with blackened edges. Nucleolides blue or brown-green. FIGURE 29 - Octopus neurons stained with osmium by the Kopsch method for the 'Golgi apparatus' and counterstained with acid fuchsin. The lipochondria are red and have osmium staining material associated with them.



FIGURE 30 - Mitochondria in nerve cell of spinal cord of a rabbit. Fixed formalin, post-chromed embedded in Carbowax and stained by a silver method. FIGURES 31 AND 32 - Synaptic end feet in the spinal cord of the rabbit. Fixed formalin and stained by Cajal's method, embedded in Carbowax. FIGURES 33 AND 34 - Synaptic end feet stained to show the mitochondria they contain. Fixed formalin, post-chromed, embedded Carbowax, and stained with a modified Bielschowsky's silver stain. FIGURE 35 - Longitudinal section of post-synaptic portion of giant nerve fibre of squid (see figure 36). 'Neurofibrils' are seen in the axoplasm. The axoplasm immediately below the synapse contains synaptic granules less basophil than the rest of the material. Fixed picoformal in sea water; Mallory's stain. FIGURE 36 - Low-power view of giant synapse in the squid, prepared as figure 35. The presynaptic fibres are little stained because they are poor in nucleoproteins (p. 9). They are seen lying on top of the more darkly staining part, synaptic giant fibres. FIGURE 37 - Node of Ranvier in rabbit's nerves. Staining: Bouin, Bodian, Mallory. Axons purple, collagen green, myelin dissolved away. FIGURES 38 AND 39 - Nerve fibres of a frog, stained supravivantly with methylene blue, which enters only at the nodes. Myelin lightly stained brown with osmium tetroxide.

demonstration that they occur within the cell makes it unnecessary to postulate the presence of large volumes of extracellular water in the tissues [22].

The classical means for revealing the materials of the Golgi apparatus involve fixation and staining with osmium or silver (figures 27 to 29). The relation of the networks shown by these methods to the bodies stained with neutral red has been much discussed. M. Parat [28] and others considered that the Golgi apparatus seen after fixation consisted simply of the distorted neutral red vacuoles. This view is certainly not wholly correct, because other material may be associated with the lipochondria. The situation differs in different cell types; moreover the effect of neutral red on the cells has to be taken into consideration. In the cephalopod neurons that we are now considering, neutral red bodies are certainly closely associated with the structures revealed after fixation by the Golgi methods. After such procedures the spherical bodies can be seen around the nucleus, usually lightly stained with osmium or silver (figures 27 and 28). Sometimes the bodies are crescentic, presumably as a result of distortion during fixation. The bodies at greater distance from the nucleus are often larger, as in the living cell, and may sometimes be seen to run together to make a network.

These bodies are not always the most deeply coloured objects seen after staining with these metals. Darker granules are found in the same regions, but between, and often on the surface of, the larger neutral red bodies. By suitable staining it is possible to colour the larger bodies with acid fuchsin, showing that they are distinct from the granules stained with metal (figure 28).

The fact that the Golgi apparatus includes a more darkly staining and a lighter component has long been known, not only in this case but also in others. Histochemical tests have now shown that various other components may be present, for instance a mucopolysaccharide [8]. Evidently, then, we are dealing with an aggregate of materials of some complexity, and such multiplicity of parts would be in keeping with the conception that the Golgi materials constitute another of the fundamental molecular groupings by which the stability of cell organization is ensured. The problem of naming this constituent remains difficult. Spheres of partly lipid or phosphatide nature are a common feature of the material and a strong case can be made for referring to these as lipochondria [3], but this name tends to obscure the chemical

complexity that these aggregates possess in many, perhaps all, cases. The term Golgi complex expresses this not inappropriately, but has an unfortunately mysterious ring.

Material of this type is probably present in all animal and plant cells, but it is still not easy to make statements about the significance of the various forms that it takes. In the neurons of some molluscs the lipochondria in the perinuclear region show a brilliant yellow or orange colour (figures 11-13) [23, 36]. Red haemoprotein granules are also present. The spheres described above in cephalopod ganglia may show a faintly yellow colour. The strongly yellow bodies take up neutral red, as do the comparable less coloured cephalopod granules. They also stain lightly with osmium tetroxide (figure 8) and have the capacity of swelling and shrinking reversibly with changes in the tonicity of the medium. There is therefore every reason to think that in all molluscan neurons the lipochondria contain some yellow pigment. The pigment is soluble in alcohol and may be a carotenoid [6]. Irradiation of dark-adapted neurons of *Aplysia* with light of the wavelength absorbed by the pigment increases their reaction time [2]. This tells little of the normal function of lipochondria, but suggests a connection between the photochemical processes in the eye, which involve carotenoid derivatives, and more general cellular metabolism.

There have been many speculations as to the function of the Golgi materials, mostly connected with the fact that changes are seen in them during certain phases of synthesis by the cell and that some secretory granules arise in connection with them. For example, L. G. Worley and E. K. Worley [38] showed that the individual bodies grow and can rapidly produce particles of either protein or fatty material in developing larvae. A further clue is that there are oxidizing systems associated with these granules [40], and this suggests a connection with the possible capacity of carotenoids as part of a redox system. If synthetic enzymes are localized in the lipochondria they would presumably need associated redox systems. It may be that the structure of each lipochondrion is such as to allow synthetic enzymes to work in one direction by assuring segregation of the products of reaction within the vacuole.

Interesting changes are seen in the Golgi materials of nerve cells after severance of the axon. Great quantities of very small lipochondria appear near the nucleus (figure 26). These may be connected with the process of synthesis that



FIGURE 40 — Electron micrograph of part of the cell body and a dendrite from the spinal cord of a rabbit.

accompanies regeneration of the nerve fibre. Unfortunately it is not known how these particles arise.

The condition of the Golgi material in vertebrate nerve cells remains doubtful. It was in these cells that Golgi first described his network, but it is probable that this form is an artifact of fixation, and many of the bodies stained with these methods are spheres (figure 29). Electron microscopy shows the lipochondria as electron-opaque spheres after osmium fixation (figures 1, 40, and 41). Their origin or method of formation is not known, but they are similar to the smaller electron-opaque spheres that are seen within the nucleus. Some preparations suggest that the latter may pass through the nuclear membrane. There have been frequent suggestions that lipochondria are produced by the nucleus, for instance in the formation

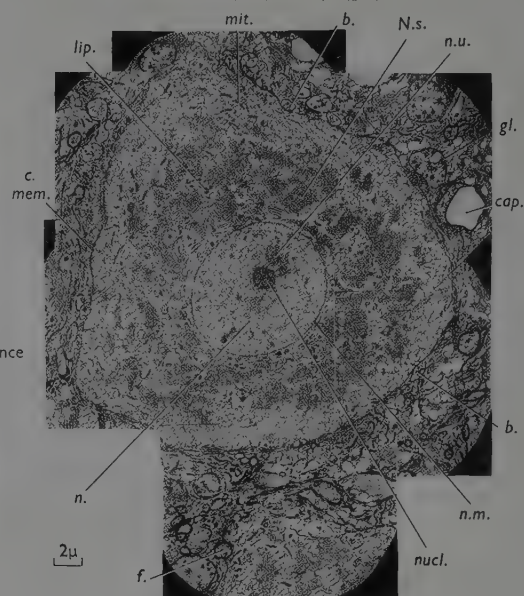


FIGURE 41 — Drawing of electron micrograph of nerve cell from the spinal cord of the rabbit. b., bouton; cap., capillary; c. mem., cell membrane; f., nerve fibre; gl., glia; lip., lipochondria; mit., mitochondria; n., nuclear sap; n.m., nuclear membrane; N.s., Nissl substance; n.u., DNA; nucl., nucleolus.

of yolk [39]. It is therefore a reasonable hypothesis that they are organized particles produced by the nucleus under the ultimate control of the genes.

The lipochondria are largest and most numerous in the region of the cell body around the nucleus. They may be associated with endoplasmic reticulum, indeed occasionally they lie at the centre of concentric lamellae of the latter. They extend into dendrites, but are smaller and less numerous there, and they are not found in the axon. This distribution is in agreement with the suggestion that they are particles produced by the nucleus and capable of initiating particular synthetic activities in the cytoplasm.

MITOCHONDRIA

These bodies, usually rod-like, are the best known of all the discrete cytoplasmic constituents. They carry a large part of the cytochrome oxidase system of cells, and many other enzymes beside [33]. They are certainly actively concerned in many metabolic processes. There is still little information about the origin or growth of mitochondria or how the reactions they ensure are controlled. The mitochondria in nerve and other cells contain

a system of internal septae (figures 1 and 2). They are present in all parts of the cell but at varying densities. They are plentiful in the region surrounding the nucleus (figure 30) and interspersed between the large granules of Nissl substance in the cell body. At the edge of the cell body, where the endoplasmic reticulum appears as separate vesicles, the mitochondria are numerous and are often in close contact with elements of the reticulum. They are also numerous in the dendrites. They are less abundant in the substance of the axon, where they lie as very elongated rods along the axis of the fibre. Mitochondria are again very abundant in the finest terminations of the axon, in the terminal end feet (figures 33 and 34), which make the synaptic endings with the motoneurons of the spinal cord.

The mitochondria clearly exemplify formed complex aggregates, each determining reactions that go on in its neighbourhood. Their mode of formation is unknown, but it may be that they originate at the nucleus (see p. 8), or at the cell surface (p. 17), and are transmitted through the cytoplasm. They are certainly most important in controlling the metabolism of each part and in determining in what reactions a molecule entering that region will become engaged. During the period of active synthesis that occurs in a nerve cell body after section of the axon the number of mitochondria is increased [17].

NEUROFIBRILS

Histological techniques often show the presence of sharply defined fibres within the axon. Fibrils have been seen in living nerve cells in tissue culture, but nevertheless it is probable that they do not usually occur as large discrete entities in normal conditions. The material of cell body, axon, or dendrites may show signs of longitudinal orientation (figure 35). If a giant nerve fibre of a squid or cuttlefish is examined alive in sea water very faint signs of longitudinal striation are seen. If the fibre is then damaged by puncture the striations become much more definite. It seems likely, therefore, that the neuronal material contains elongated particles, which readily fall together to make more definite fibrillae. Fine threads 6–10 μ in diameter and of indefinite length have been seen by electron microscopy by various workers [31, 27]. Such appearances are indications of the presence of molecules able to form long particles. There is little that can be said at present about their significance, but it seems possible that they constitute a framework or cyto-

skeleton for the long nerve fibres. If this is so they would not be classed as agents of the intracellular communication system in the sense of carrying signals that initiate specific types of activity, as do the granules previously considered. Yet they may form an essential part of the communication system if the long molecules assist the transport of the signalling particles either by directing the flow or by actively furthering it.

THE NERVE-CELL SURFACE

The action potentials that are the characteristic signals with which the nerve cell operates are set up and propagated by its surface, and the properties of the outer boundary of the cell are therefore of special importance. The membrane is so thin that almost nothing was known of its appearance before the advent of the electron microscope. With the latter it appears as a continuous double membrane of the order of 10 $m\mu$ thick over the whole surface of the cell body and dendrites.

The conditions at the axon surface are complicated by the presence of the covering layers of myelin. Axons seldom or never run free, but are covered by the protoplasm of the Schwann cells. The membranes between the protoplasm of the Schwann cell and the axoplasm are elaborated to make the lipoprotein lamellae that provide an insulating surface to the fibre. In the fully medullated nerve fibres of vertebrates the myelin layer, 2 μ or more in thickness, covers the axon except at the nodes of Ranvier, which are separated by distances of a millimetre or more (figure 37). The only part of the axon that is in immediate interchange with the surroundings is the minute region at the node. The current generated at one node thus passes to and excites the next, and the velocity of propagation is thereby increased by the sheath. If a medullated fibre is stained with methylene blue the dye enters only at the node, the myelin preventing access to the rest of the fibre (figures 38 and 39).

In smaller vertebrate nerve fibres, and in those of most invertebrates, there are no nodes. Nevertheless a sheath with several layers is usually present. B. B. Geren and F. O. Schmitt [16] have recently shown that the protoplasm of the Schwann cells around lobster nerve fibres contains several membranous layers. The innermost of these is in direct contact with the surface of the axon, and, indeed, constitutes the outer membrane of the latter (figure 2). This locality is of particular interest because it is here that the interchanges take place by which the nerve fibre is charged and discharged,

potassium ions being pumped inwards for charging and sodium outwards [19]. It is therefore of special significance that numerous mitochondria occur in the outer region of the axoplasm, beneath the membrane. Moreover, Schmitt and Geren observed that the innermost layer of the Schwann cell is folded in a manner that suggests that vesicles may become nipped off to form the mitochondria that are especially numerous in the outer layers of the axon (figure 2). If this is true we have here an exceptionally clear example of an interchange that takes place in a quantal manner, by the transfer of quite highly organized units.

At the motor end plate, where the nerve fibre stimulates a muscle, there is an elaborate specialized portion of the neuron, which cannot be here described in detail. Numerous mitochondria are again involved, and the region is one of great metabolic activity. The arrival of action potentials along the nerve fibre serves to trigger off the release at the end plate of sufficient acetyl choline to fire the muscle fibre. Once again quantal processes are involved. P. Fatt and B. Katz [15] have shown that unit quantities of acetyl choline are continually released at the end plate, even at rest. The arrival of the nerve impulse serves to increase the rate of release of the quanta above a threshold level. It is not yet known whether these quantal units are determined by the separation of visible formed bodies from the nerve ending to the muscle. The fact that there are aggregations of bodies at the end plate suggests that this may be so [30]. In any case we see once again evidence that the stability of a part of the living system is assured by the operation of release of units composed of relatively complicated molecular aggregates.

SYNAPTIC GRANULES

There is some evidence that the stimulation of one neuron by another is also accomplished by the release of formed units of material. Granules stainable with acid fuchsin have been known for some time to occur at the synapses of giant cells [4, 43]. In the squid these granules can be seen in the presynaptic endings (figure 15), between the two surfaces (figure 14), and within the post-synaptic neuron (figure 35). There is no certainty that the granules are composed of the same material in all these situations; but they all stain alike, and no other fully comparable material is found elsewhere in the neighbourhood. There is therefore some reason to suppose that in this situation, too, signals are transmitted by the release of standard unit particles.

At the synapses in the spinal cord of mammals the presynaptic fibres are filled with conspicuously large granules (figures 2, 33, and 34). These may be mitochondria or perhaps some more specialized material. Clear evidence of the transfer of particles to the postsynaptic cell is as yet wanting in this case, but some suggestive signs of it have been reported [14].

In a few instances nerve fibres seem to function mainly by the transport of chemical signals along their whole length. Such granules of neurosecretion are found in the fibres that innervate the pituitary body of vertebrates and some glands in invertebrates [21]. Presumably this form of signalling is more effective than the conduction of nerve impulses for the continuous maintenance of a steady level of secretion by a gland. Its interest in the present context is that the stimulating product is transmitted in the form of discrete granules.

CONCLUSION

There is much reason to think that part, at least, of the cellular organization can be described by treating it as a two-way communication system. Events at the cell surface determine changes immediately within the cell membrane. These set in operation other changes proceeding inwards, which ultimately influence the operations of the nucleus. This, in turn, modifies its actions, sending out signals that appropriately alter the reactions in the cytoplasm.

The presence of various types of formed particle in the cell is entirely in accordance with the hypothesis that some form of signalling system is involved—indeed, were the particles not known, their presence could be inferred from the fact that distant parts of the cell maintain a stable pattern of organization under the influence of the nucleus. It is not a question of whether cells are communication systems, since the elementary facts show that they are: the problem is to discover how the information is transmitted. Something must be sent from the cell body down the nerve fibre, for the latter ceases to maintain its steady state if it is cut off. Conversely, something must be transmitted towards the nucleus, for after severance of the axon it proceeds to increased protein synthesis.

It is likely that many of these effects depend upon a transmission system composed of specific pre-selected control particles, the mitochondria, lipochondria, microsomes, and endoplasmic vesicles.

These particles are certainly not distributed uniformly through the nerve cell. No figures are available for their frequencies in the different

parts. If such figures could be obtained, especially from cells in different conditions, they might throw light on the problems of where these bodies are formed and what determines their number in any region. It is not clear whether there is any relationship between any of these types of particle and the granules that are found at synaptic surfaces, but there is enough evidence to suggest that not only these synaptic granules but all the particles are units by which the cell maintains and transmits a stable pattern. It has often been suggested that the cytoplasmic particles are self-reproducing, especially the mitochondria. There is at present little evidence for this, although until we know how they are formed it remains a possibility. The presence of heritable determinants in the cytoplasm is well established (plasmagenes). There is some evidence that some cytoplasmic particles are formed at or near the nuclear surface. It may be that the nucleus provides the signals that ensure maintenance of a steady state by liberating these bodies into the cytoplasm. These instructions must control the metabolism of parts of the cell that are several feet away in the case of a long nerve fibre.

It would not be surprising, therefore, to find that they are carried in the form of discrete aggregate particles, which will transmit the instruction more accurately than will a continuous flow of molecules.

It is impossible at present to say more about how these particles arise or how their composition is regulated, as it must be if each is to function as a signal, producing a definite effect in some distant place. We need more information about their site of formation and transport in the cell before the comparison with a communication system can be further developed.

There is enough evidence available to suggest that cellular organization can be described largely in terms of the various specific collections or packets of molecules, which are the means by which the past history of the race, transmitted by the genes, controls daily metabolism.

The electron micrographs of figures 1(a), 2(4), 40, and 41 were taken by R. G. W. Wyckoff, to whom the author is greatly indebted. His thanks are also due to Mr J. Armstrong for the colour photography and to Miss E. R. Turlington for the drawing of figures 2 and 41.

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Thoughts on optical activity

H. M. POWELL

It is a tribute to the genius of Pasteur that his main conclusions on optical activity remain unchallenged and his three methods of resolving optically active substances found no significant addition for nearly a century. In recent years, however, new methods of resolution have been used. New classes of optically active materials arise when a surrounding molecular structure will include a molecule more readily as one enantiomorphous form than as the other. The existence of other kinds of optically active substances can also be foreseen.

That substances of certain chemical constitutions can be obtained in two forms differing only in that their molecules are related as non-superposable mirror images of each other was discovered by Pasteur [1] many years before precise structural formulae had been assigned to simple organic compounds. The idea that molecular shapes may have left and right mirror-image forms is perhaps very much older, since Lucretius wrote [2]:

*fac enim minimis e partibus esse
corpora prima tribus, vel paulo pluribus auge;
nempe ubi eas partis unius corporis omnis,
summa atque ima locans, transmutans dextera laevis,
omnimodis expertus eris, quam quisque det ordo
formai speciem totius corporis eius . . .*¹

In other passages the poet describes corpuscles that are solid enough, and in a later book talks of turning a wet plaster cast inside out in order to form a mirror-image of the familiar kind, with the right eye appearing on the left. Although in the lines quoted Lucretius does not mention back and front, he also does not state the shape of the three least parts, and any suspicion that this corpuscle is two-dimensional, and thus superposable on its mirror image, may be disregarded.

Some natural substances give solutions such that when plane-polarized light is passed through them the plane in which the transverse light vibrations may be imagined to take place is rotated through an angle about an axis coincident with the direction of the light. The extent of the rotation is proportional to the amount of material that the light has passed through, and the effect, thus shown to be unconnected with any action at the surface, must be brought about by the molecules. Crystals of plant-formed tartaric acid and its salts show

hemihedral faces and are not superposable on their mirror-images. Racemic acid, indistinguishable in composition and in some properties from tartaric acid, does not rotate the plane of polarization, has a different crystalline form, and does not show hemihedral faces. Its salts also, as ordinarily prepared, show no hemihedrism, with the exception of sodium ammonium racemate, which Pasteur found to give two sets of hemihedral crystals. One of the latter was identical with the corresponding salt made from natural tartaric acid, and the other was its mirror-image form, previously unknown. The crystals may be separated by hand, and from the second sort there may be obtained a variety of tartaric acid differing from the ordinary one virtually only in that its solution rotates the plane of polarization to the same extent but in the opposite sense.

Many substances are now known to exist similarly in *dextro* and *laevo* forms, and in all cases the molecule, for one reason or another, has a three-dimensional form which is not superposable on its mirror image. It may have no symmetry, but, like a propeller, it may have one or more axes of rotational symmetry: on rotation about such an axis through an angle of $360^\circ/n$ (n being a small integer) the molecule appears the same as in the starting position. It cannot have any symmetry which implies a mirror-image operation. Such a body is conveniently described as dissymmetric.

Almost all laboratory reactions for making these substances yield equal amounts of *dextro* and *laevo* molecules and the product gives an optically inactive solution, since molecules which bring about rotation to the right are counteracted by the equal number which cause rotation to the left. This does not apply when one of the starting materials is itself used in an optically active form, but equal amounts of both enantiomorphs are produced by nearly all methods of forming dissymmetric molecules from others which are optically inactive.

¹ For suppose that corpuscles consist of three least parts, or add a few more. When, by attaching these at top and bottom and transposing right and left, you have tried every possible shape that methodical arrangement of the parts can confer on the form of the body as a whole . . .

No special influence is required to form a dissymmetric molecule, but the space relationship of the reacting molecules at the appropriate times results in one or other mirror-image form. If the reaction is not affected by a dissymmetric influence, either from within or without the molecule, there is an equal chance that the *dextro* or *laevo* form will result. Since on a laboratory scale the number of molecules involved is immense, the product will differ from an equal mixture only to a minute, optically undetectable, extent.

Spontaneous resolution of such racemic mixtures on crystallization has been observed comparatively rarely. It is known of some substances, and thought to be true of many others, that their crystalline structures contain equal numbers of *dextro* and *laevo* molecules in the same way as most of the salts of racemic acid originally examined.

To separate a *dl* mixture Pasteur proposed to apply a dissymmetric influence which would act differently on the two forms. He achieved this [3] in one way by acting on a mixture with another substance which was already available in either a *dextro* or *laevo* form. A *dl* acid on reaction with a *d'* base may give the products *dd'* and *ld'*. These are not mirror-image forms, and they differ in solubility and other properties like any other pair of non-enantiomorphous substances. Consequently they may be separated by ordinary methods.

Another of Pasteur's methods [4] of obtaining optically active material from a racemic mixture involved the use of living organisms. When ammonium racemate was subjected to fermentation the yeast caused the salt of one hand only to ferment.

A number of other methods practised or suggested involve the application of a dissymmetric influence. For example, some media show unequal absorption of circularly polarized light according as it is left- or right-handed, and in suitable mixtures this might lead to selective destruction of one enantiomorph [5]. Photochemical reaction under the influence of left- or right-circularly polarized light may favour the production of one form [6]. Another method uses adsorption of the substance on surfaces which might be expected to behave differently towards right- and left-handed molecules, e.g. the surfaces of crystals, like quartz or cane sugar, which may be obtained in forms not superposable on their mirror-images [7]. A recent exploitation of supersaturation phenomena resulted in the resolution of large amounts of material such as racemic threonine [8]. Only a small quantity of one optically active form is required to start a series of operations which give

alternately crops of the *dextro* or *laevo* forms. Large quantities of the two forms may be separated, but it is the dissymmetric influence of the original active material that makes the procedure possible.

Pasteur repeatedly emphasized a distinction between the chemistry of living matter and that of laboratory reagents. Briefly, he said that, in contrast to artificial laboratory products, the essential products of life are dissymmetric in such a way that they cannot be superposed on their mirror images. He lists cellulose, starches, gums, sugars, tartaric and malic acids, morphine, strychnine, turpentine, albumen, and gelatine, among others, as dissymmetric. Very vigorously he refuted claims for exceptions based on resolution by living organisms, pointing to the dissymmetry introduced by the organism itself.

Pasteur did not suggest that dissymmetric substances cannot be synthesized; on the contrary, he went to great efforts to achieve it through the application of dissymmetric forces. This he attempted by a variety of methods, some of which he later considered crude. He looked upon the universe as dissymmetric, saying that if the solar system, with the proper movements of the heavenly bodies, were placed before a mirror its image would not be superposable on the reality. Similarly the Earth, with its magnetic poles, provides an object not superposable on its mirror-image. In order to imitate nature, he said, it is necessary to have recourse to dissymmetric forces, as in the action of solenoids, of magnetism, of dissymmetric movements of light, and the action of substances which themselves are dissymmetric. At Strasbourg he had powerful magnets constructed by Ruhmkorff, and at Lille he made use of turning movements effected by clockwork. In view of the opposite polarities associated with magnetism he felt justified in posing this question concerning the formation of hydrocarbons from the carbon in a steel magnet [9]: '*L'aimant, pénétré de ce je ne sais quoi qui le fait aimant et qui est, j'imagine à image non-superposable, ne donnerait-il pas, au moment de la mystérieuse combinaison de son carbone avec l'hydrogène, des molécules dissymétriques? J'irais plus loin; je voudrais comparer les carbures d'hydrogène formés simultanément et séparément par l'attaque des deux pôles d'un aimant.*' He wondered what would happen if albumen, cellulose, and other constituents of microbes could be replaced by their mirror-image forms.

Some products of life are not dissymmetric and many inorganic compounds showing dissymmetry have been synthesized, but since the time of

Pasteur there has been speculation as to how nature carries out much of living chemistry in a dissymmetric way. W. H. Mills [10] has related it to a process of growth. A minute difference in the proportion of *dextro* and *laevo* molecules, such as could occur in a small unit of a living system, would ultimately lead to dissymmetric chemical changes more efficient than the corresponding set of reactions with racemic materials. E. Havinga [11], who nevertheless has a possible answer, remarks that the question as to how the first dissymmetric material can have been brought into being in living organisms is in itself not overwhelmingly urgent. This problem may be combined with the great mystery of the first life, and one may just as well suppose that the first life was dissymmetric as that the first living matter came into being and that it later made use of optically active material.

However this may be, there is a special interest in processes which result in the production of optically active materials without deliberate introduction of any other substance in a resolved form.

When W. J. Pope and S. J. Peachey [12] used *d*-camphor-sulphonic acid to resolve methylethyl-*n*-propyl tin they obtained the whole of the tin complex salt in the *d* form without the *l* form accumulating in the mother liquors. This happened because in solution there was rapid racemization of the complex which was removed in one form only into the crystal, where it does not racemize. Although this experiment required the use of the optically active camphor derivative it shows how rapid racemization may be exploited to achieve a form of asymmetric synthesis.

The nucleation of a saturated solution of a racemate by a crystal containing an excess of one optically active form has been observed very often. For example, L. Anderson and D. W. Hill [13] found that the first material deposited from a solution of racemic atropine sulphate usually had the *l* form when the crystallization was carried out in a laboratory where the *l* form had been racemized. Although in such circumstances the laboratory atmosphere would supply seeds, it seems that in some experiments of this kind crystallization is induced by material that is not optically active. E. Darmais [14], in 1953, published details of some earlier experiments in which an optically active alkaloid could be obtained from its racemic hydrochloride by precipitation with pyridine. This is attributed to preferential nucleation, but no optically resolved materials are used to start it. R. C. Ferreira [15] achieved a slight optical separation of narcotine in this way.

Havinga carried out an experiment with optically inactive material. Methylethylallyl-phenylammonium iodide crystallizes with one molecule of chloroform as a conglomerate of *dextro* and *laevo* crystals. At room temperature a solution of the optically active form racemizes rather slowly, showing a considerable rotation at the end of five weeks; by very slow cooling of a racemic solution a crystal, or crop of crystals, of one hand only was obtained.

Recently, resolutions without the use of optically active materials have been accomplished with the aid of crystalline molecular compounds.

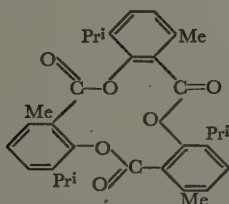
In many crystalline molecular compounds molecules of two different kinds together form the lattice; the complexes here considered have no chemical bonding between the components. In a special class of these compounds one component forms a structure enclosing a set of spaces in which the molecules of a second sort are contained. Whether a particular molecule can be so enclosed depends on its shape and size, since it must, for enclosure, be able to fit into the available cavity. The formation of such compounds may be applied to separate substances which are chemically and physically similar but have different molecular shapes; as a special case of this, *dextro* and *laevo* molecules may be separated. If the surrounding structure consists of an arrangement of atoms which is not superposable on its mirror-image then the cavities also will be different from their mirror-images, and thus may be able to include one form of some other molecule although they reject its enantiomorph. Dissymmetry of an enclosing structure may arise when the cage-forming material is optically active, optically inactive, or racemic.

An example of the enclosing structure being itself optically active is afforded by the cyclodextrin inclusion compounds [16] in which molecules are enveloped in the large ring system of the cyclodextrin molecule derived from dextrose. A partial optical resolution of racemic substances such as mandelic ester has been made by means of these compounds. It depends on inclusion, but the reagent used is in this case optically active.

Molecules of a substance which is optically inactive in solution may in the crystal build up enantiomorphous structures, for example by arrangements in left- or right-handed spirals. Either form could crystallize and both could appear together, but preferential nucleation may cause a predominance of one form in the product. Examples are provided by the urea adducts with aliphatic molecules. The spaces in which the

molecules are enclosed are, to a first approximation, a set of uniform cylinders arranged as the spaces of a honeycomb. The walls of the cylinders are in reality made up of a hexagonal spiral of urea molecules. Although the difference from a uniform cylinder does not appear to be very great, the adducts can be used to separate secondary octyl chloride and other substances into their enantiomorphous forms [17]. The extent of resolution is not clear, though it is reported that the process must be repeated a number of times.

The cage structure may be composed of the optically active molecules of a substance which is used as a racemate. Such a substance could form a non-enantiomorphous cage structure composed of equal numbers of *d* and *l* molecules; in this case the cavities would not be dissymmetric or they would, like the enclosing molecules, occur in mirror-image pairs. Such a structure would not be expected to be selective for the *d* or *l* form of an enclosed component. Alternatively, on formation of the crystalline molecular compound there may be separation into a conglomerate of *d* and *l* crystals. If one crystal of the product contains only the *d* form of the enclosing molecules this is necessarily enantiomorphous. Its cavities will be the non-superposable mirror-images of those in the *l* crystals which constitute the other kind in the conglomerate. Tri-*o*-thymotide (represented below) and its adducts illustrate this case [18].



Tri-*o*-thymotide is itself optically active, and it crystallizes alone as a racemate. Although it has been resolved, it can in effect be used only as a mixture of *d* and *l* forms, since it racemizes very rapidly in solution, having a half-life period of a few minutes at room temperature. From many solutions it is obtained in the form of crystalline adducts with solvent. These have a variety of crystalline structures. Some are racemates, but many are conglomerates of *d* and *l* crystals. These crystals are not distinguishable by any enantiomorphous face-development, but they can be shown by X-ray diffraction experiments to belong to enantiomorphous space-groups. In any one crystal, tri-*o*-thymotide molecules of one hand only are present. Racemization does not occur in

the crystal at ordinary temperatures. In the crystalline adduct the tri-*o*-thymotide molecules are arranged in a spiral so that one of the enantiomorphous crystals has molecules of one hand in a right-handed spiral and its mirror-image has the opposite hand of molecules arranged in a left-handed spiral. Optically inactive molecules such as benzene or *n*-hexane may be enclosed in the cavities, and by reason of their symmetry will fit equally well into either of the structures.

One form of optical resolution is that of the tri-*o*-thymotide itself when the adduct with benzene is formed. By slow cooling the whole yield may be obtained as one or more large crystals. Any one of these necessarily contains only one hand of the tri-*o*-thymotide molecules and is thus resolved by a process which is a simpler form of Pasteur's first method. In any case, once a crystal nucleus forms it tends to produce more nuclei of its own kind, and either spontaneously, or with the help of deliberate seeding, a crop of predominantly one kind of crystals may be obtained without the need to grow large single crystals. Since the half-life period for racemization is short compared to the time for growing the crystals, all the tri-*o*-thymotide removed in some experiments is of one hand. The only thing added to the originally racemic tri-*o*-thymotide is the optically inactive benzene.

The enantiomorphous character of the cavities in suitable molecular compounds may also be used to separate racemic mixtures. One series of tri-*o*-thymotide molecular compounds, formed only with molecules which do not exceed a certain critical size, has closed cavities. The dimensions of the dissymmetric secondary butyl bromide molecule permit its enclosure. The product of the slow cooling of a solution of tri-*o*-thymotide in racemic secondary butyl bromide in general contains unequal amounts of left and right crystals. Either with or without seeding it can be obtained predominantly in one form, and the fraction of the crop having the *d* or *l* form may be estimated by comparison of the optical activity with that of completely resolved tri-*o*-thymotide. This is possible because the initial rotation of the tri-*o*-thymotide solution is very much greater than that of the enclosed material. The secondary butyl bromide recovered is found to be optically active. The optical resolution has been brought about without the use of an optically active material in resolved form. The extent of the resolution is found to be the same as that of the unequal conglomerate of the tri-*o*-thymotide that encloses it.

This is what would be expected if each cavity entirely excluded one form of the secondary butyl bromide. Such behaviour is to be expected when the empty space is, like the space in a boot, not superposable on its mirror-image and the enclosed molecule, like the normal foot, fills most of the space. A sufficiently small left foot will go into a right boot, and analogous behaviour may be expected in some inclusion compounds.

For ordinary dissymmetric substances the crystalline forms known are racemates, *d* and *l* forms in equal or unequal conglomerates, and a variety of mixed or complex crystals, pseudo-racemates and twinned forms. The examples of optically active molecular compounds, which do not exhaust the possible combinations of active and inactive constituents, suggest that there may be other types yet to be discovered.

A crystalline molecular compound formed by the building of a complex lattice, but not dependent on inclusion of one component, could have both partners racemic, one racemic and one optically active, or both optically active. If they are stoichiometric, the rotations of the various forms will be interrelated. A special case would be that of a structure containing *d* and *l* forms of the same substance in fixed but unequal amounts. Crystal structures are known in which two or more geometrically different positions in the unit cell are occupied by molecules of the same constitution to form a complex pattern. There could be unequal, but fixed, numbers in different positions, or equal numbers in several different positions. Some of these forms could be optically active because the overall composition is of the form $d_n l_m$, *n* and *m* being integers. If the *d* and *l* forms are stable, the rotation of such a substance would be constant. A *dl* mixture might in some circumstances spontaneously resolve into $d_n l_m$ and $l_n d_m$

crystalline forms that might be mistaken for *d* and *l* because they have constant equal, but opposite, rotations.

As has been seen, the enclosed and enclosing components of inclusion compounds similarly may have various optical forms. In the limiting case, when the cavities are all filled and are strictly selective for one enantiomer, there will be a definite rotation related to the nature and proportion of the components. The effects of empty spaces and diminished selectivity can be easily worked out.

Special effects may be expected in the case where the cage is closed but is large enough to hold more than one molecule of suitable size. Structures of this kind have been discovered. One case only will be considered here [19]. The cage is centrosymmetric. If it forms from solution in a racemic solvent we might expect to get some cavities with a *d* and some with an *l* enclosed molecule or, with sufficiently small molecules, cavities with one *d* and one *l* each. Provided one cavity and its contents has a negligible influence on another, these forms will be optically inactive. A curious effect can thus be foreseen. Suppose the centrosymmetric cage forms from a *d* solvent. The dimensions are such that one *d* and one *l* will fit, but once the cavity contains a *d* molecule the remaining space is the wrong mirror-image form for a second *d* molecule, which might be as rigorously excluded as the wrong form of secondary butyl bromide in the tri-*o*-thymotide adducts. The molecular compound formed from *d* or *l* solvent should therefore include only half as much material as that obtained with racemic solvent. Partly resolved mixtures should give molecular compounds of intermediate compositions, and thus the extent of an optical resolution of a previously unresolved substance might be estimated.

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Muslim mechanics and mechanical appliances

H. J. J. WINTER

The story of the presentation of a water-clock to the emperor Charlemagne by the caliph Hārūn al-Rashīd is well known, and the Arabs and Persians excelled in the making of such contrivances, but an understanding of the state of the science of mechanics as a whole in medieval Islām is difficult to attain. It comprises not only the legacy of Greek thought and experiment, with practical applications in evidence from the palace of Alhambra to the mosques of Samarkand, but a few remarkable advances springing from its own genius.

Of the Greek authors whose writings on mechanics were rendered into Syriac and Arabic during the period of translation and assimilation (roughly A.D. 750–900), Euclid, Archimedes, Apollonius, Hero, and Philo were the most revered. The ‘Mechanics’ of Hero of Alexandria (translated about 860 by the Nestorian Christian, Qusta bin Lūqā of Baalbek, for the caliph al-Musta‘īn), and the ‘Pneumatics’ of Philo of Byzantium, the translator of which is unknown, inspired both new writings and a wide range of practical devices. Thus the Banū Mūsā, the three sons of Mūsā ibn Shākir (who was himself a friend of the caliph Al-Ma’mūn), were the authors of the ‘Book of Artifices’ (*Kitāb al-ḥiyāl*) [1], which describes one hundred pieces of technical equipment. The greater proportion were novelties, following Philo, and can be classed as mechanical toys, but some of the inventions developed from the ideas of Hero had great practical significance. In medieval Islām during the ensuing period (c. 900–1100)—when science was widely accepted and new advances were being made—applications were made of all the simple machines such as the lever, wheel and axle, pulley, inclined plane, toothed wheel, endless screw, siphon, and pump, together with the water-wheel and windmill.

The so-called Golden Age of Islamic science owed its importance largely to the Persian contribution. The language of Iran had assumed a new significance, and a creative spirit was being born in her scholars as the tenth century dawned. Among those who wrote eloquently in this language rich in imagery were Ibn Sīnā (980–1037), Abū Raiḥān Al-Bīrūnī (973–1048), and ‘Umar Khayyām (d. c. 1123), though their scientific works are largely in Arabic, a medium better suited to terse and deductive argument. To the Arabic language we also owe a great debt for

its preservation of the classics of Greek science.

In the realm of mechanics Ibn Sīnā is noted mainly for his theoretical postulates, our subject representing to him the lowest level of a great scheme of speculative philosophy. These postulates are highly ingenious and sometimes correct. He wrote in *Al-kitāb al-naǧāt* that ‘no body begins to move or comes to rest of itself’, a clear statement of the principle of inertia; that ‘time cannot be imagined without movement’; and that force is measurable only in terms of its effects. Again, in any simple machine, ‘what is gained in power is lost in speed’. Ibn Sīnā also regarded the problems of statics as fundamentally those of dynamics, whence he proceeded to explain the impact of bodies from the standpoint of dynamic forces acting from within the bodies. But in one respect his theory of mechanics proved inadequate, for he thought only in terms of uniform velocity, as did Aristotle and Al-Kindī before him. By regarding time as continuous, and as being interpreted in terms of the ‘quantity of circular motion’ of the celestial sphere, he was diverted by these basic assumptions from any consideration of either acceleration or centrifugal force. The significance of Newtonian mechanics, and the reason why it enabled the foundations of modern science to be established, rest precisely in these two latter phenomena, whereby the false postulate that a prime mover or force is required to maintain a body at a uniform velocity in the line of action of the force was overthrown. Despite such weakness in his postulates, Ibn Sīnā was able to work successfully in the immediate practical field, and is credited with a device similar to the vernier.

Al-Bīrūnī, a man of deep erudition and an experienced traveller, is noted especially for his accurate determination of the specific gravities of eighteen precious stones and minerals. These

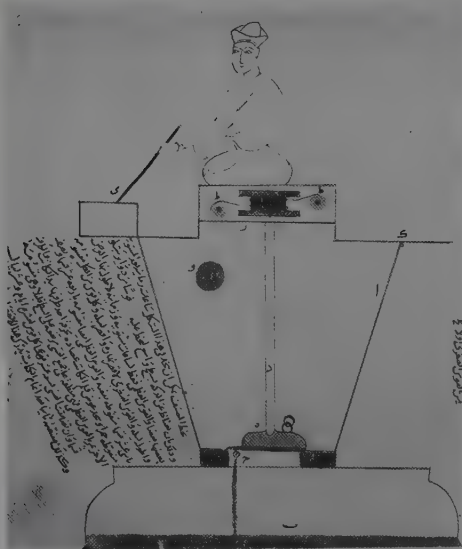


FIGURE 1—A water (beaker) clock in Al-Jazari's treatise. (From MS. Graves 27, Bodleian Library, by courtesy of the Librarian.)

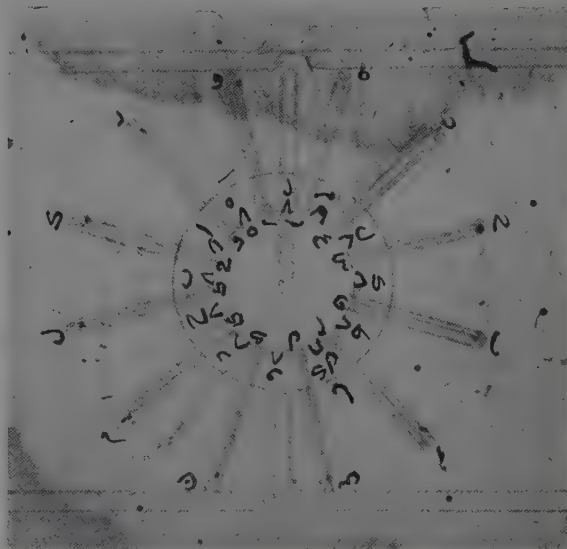


FIGURE 2—Diagram of a Persian water-wheel. (From Arabic MS. 351, Rylands Library, Manchester, by courtesy of the Librarian.)

results he studied and tabulated systematically, and it is significant to note that no such tables appeared in Western Europe until the seventeenth and eighteenth centuries, when Boyle's value for the specific gravity of mercury, for instance, was less accurate than that known to the Arabs. Al-Bīrūnī used a 'conical instrument'—a flask-like vessel with a spout projecting from the neck—to determine the volumes of metals by displacement.

'Umar Khayyām, best known as a poet, but perhaps more deserving of recognition as the author of the finest algebraical treatise of the Middle Ages, has his place in the history of the balance, following Archimedes, Menelaus, and Muḥammad ibn Zakariyā of Ray, and preceding Al-Muzaffār ibn Isma'il al-Isfazarī and Abū'l-Fath 'Abd al-Raḥmān al-Manṣūr al-Khāzini. Since the technique of the balance became a special science in medieval Islām, as, for example, did the study of the rainbow, we shall refer to it when describing the achievements of Al-Khāzini.

An interesting essay on the vacuum was written by the philosopher Abū Naṣr al-Fārābī [2]. Until recently believed to have been lost, a manuscript of this essay was discovered in Ankara University and is now in the Ismail Sāip Collection (Series I, No. 183 (ii)). Although it refutes the existence of a vacuum it does so only with reference to two particular experiments with flasks containing air

and water, and for which experiments the refutation is, in fact, valid. What is most striking in this essay, however, is an analysis of the experimental results based upon the elasticity of the air. Indeed, one of the joys of the historian of science who is able to interpret medieval Oriental manuscripts is that of finding among many pages of tedious matter some angle of approach, or perhaps a discovery, unknown to the Latin West. On the other hand, one learns to receive the views of earlier writers on the history of science with caution. Thus Humboldt attributed to Ibn Yūnus the application of the pendulum to the measurement of time, a statement which the writer has failed so far to substantiate from original manuscripts and which is probably untrue. Though the Arabs had splendid water-clocks, and study of the history of their science is always liable to reveal surprising achievements, as in Al-Khāzini, a precursor of Galileo seems unlikely.

Of the later Islamic treatises on mechanics two are outstanding, namely *Al-Kitāb fi ma'arifat al-ḥiyāl al-handasiya* (The book of the knowledge of ingenious geometrical (mechanical) contrivances) [3] by Abū'l-'Izz Isma'il ibn ur-Razzaz al-Jazarī Bādī'az-Zamān, and *Al-Kitāb mizān al-hikma* (The book of the balance of wisdom) [4] by Al-Khāzini of Merv. The former is by far the less original but serves as a summary of the various forms of contemporary apparatus; its author was primarily

a craftsman, and had advanced somewhat in technique beyond Hero and Philo, being able to use with advantage the work of his Muslim predecessors. Completed in 1206 for the Urtuqīd Sultān Maḥmūd, ruler in Amida—Al-Jazari had been in the service of the dynasty since 1181–82—the book was held in esteem by three Urtuqīd Sultāns and later translated into Persian and Turkish. Main interest centres upon elaborate water-clocks for telling the hours and hydraulic apparatus used in the raising of water. A knowledge is shown of the action of paddles, cogwheels, and revolving shafts. In a typical water-clock a copper beaker is initially full, the float being at the surface of the water and the weight at the bottom; as the beaker empties the float sinks and the weight rises, thus rotating a central spindle. The rod held by the figure of a scribe passes over an engraved lid, thereby tracing the passage of the hours (figure 1).

In the year 1860 there appeared in the *Journal of the American Oriental Society* translations of two remarkable works—the version of the *Sūrya-Siddhānta* of the Hindus, made by Ebenezer Burgess, and the treatise of Al-Khāzinī, just mentioned, first rendered accessible to Western scholars by N. Khanikoff, Russian Consul-General in Tabriz. This most important occasion has probably been forgotten by most historians of science, and it is refreshing to recall it through the second of these translations. 'The Book of the Balance of Wisdom' is one of the great treatises on mechanics. Though it deals principally, and in great detail, with the practice of accurate weighing and the determinations of specific gravities, it also discusses gravitation, flotation, and geodesy. Written at the request of Abū-l-Hārith Sanjar ibn Mālikshāh ibn Alpārslān in 1121–22 'for his high treasury', it paid particular attention to the specific gravity of alloy coinage, including *ad hoc* calibration of the balance arm, and it referred to the Archimedean solution of the problem of Hero's crown. The comprehensive nature of Muslim study of the balance may be seen from this quotation from 'The Book of the Balance of Wisdom': 'Novelties and elegant contrivances in the way of balances, such as: the balance for weighing dirhams and dinārs without resort to counterpoises; the balance for levelling the earth to the plane of the horizon; the balance known as "the even balance", which weighs from a grain to a thousand dirhams or dinārs, by means of three pomegranate-counterpoises; and the hour-balance, which makes known the passing [secular] hours,

whether of the night or the day, and their fractions in minutes and seconds, and the exact correspondence therewith of the ascendant star, in degrees and fractions of a degree.' Hour-balances consisted essentially of a long lever, one arm of which carried a vessel of water emptying in twenty-four hours, the other arm a sliding weight acting as a counterpoise and moving over the calibrations on the arm. It was usual to calibrate the right-hand arm by silver encased at appropriate distances along it, and the divisions were in units corresponding to the particular function of the balance, e.g. units of time, values of specific gravity. The Arabs were thoroughly familiar with the application in surveying and building of the parallelism of a balance beam with the plane of the horizon when the beam is evenly loaded.

A further reference to Al-Khāzinī will serve to indicate the extreme care with which specific gravity determinations were carried out. He says: 'We have made all our comparisons in one single corner of the earth, namely, in Jurjāniyah, [a city] of Khuwārazm, situated where the river of Balkh becomes low, at its outlet upon the little sea of Khuwārazm, the water of which river is well known, of no doubtful quality, and [all our operations have been performed] early in the autumnal season of the year'.¹ Not only was Al-Khāzinī aware of the necessity of removing, as far as possible, the influences of impurity and temperature variation, but he classed the balance with the astrolabe as a precision instrument demanding the greatest care in construction and maintenance, for a good balance detected 1 mithqāl in a total of 1000 mithqāl; and he suggested about 4 bazaar-cubits (2 metres) as the length of the beam, 'because length influences the sensibility of the instrument', and 1 cubit as the length of the pointer. Use of a scale and pointer was probably first suggested by Muhammad ibn Zakariya of Ray. By the time of Al-Khāzinī five thin hemispherical scale-pans, made of bronze, were in use with the balance, two being permanent, two additional, and one movable along the right-hand arm, their function being to cover all the various determinations involving weighing in liquids, etc. Commercial applications largely concerned the specific gravities of alloys and gems. Some of Al-Khāzinī's results are shown, in modern terms, in the accompanying table, and without attempting any critical analysis of their accuracy

¹Khanikoff identified this place with the site of Kuna-Urghenj. It appears that by the twelfth century A.D. the Oxus emptied into the Sea of Aral and not into the Caspian.

we see at once that they are remarkably close to values now accepted:

Gold	19.05	Fine pearl ..	2.60
	(cast)	Ivory	1.64
Mercury	13.56	Sweet water ..	1
Brass	8.57	Water (boiling)	0.958
Emerald	2.75	Olive oil	0.920

The areometer of Pappus in an accurate form was also well known to Al-Khāzīnī. Consisting of a uniform hollow copper tube, weighted at one end with a hollow cone of tin, and with two ends 'resembling two light drum skins', it floated vertically in liquids, being calibrated in both values of specific gravity and of volumes displaced. An interesting diversion made by Al-Khāzīnī was to calculate the weight of the Earth were it to consist solely of gold, for 'truly there will not be accepted as ransom from those who were infidels and died infidels as much gold as would fill the earth; for them are severe pains; they shall have no defender' [Qur'ān, III, 85].

Finally, we may examine Al-Khāzīnī's views on gravitation. Although he followed in the tradition of Archimedes, Euclid, Menelaus, Ibn Al-Haitham, and Abū Sahl al-Kūhī, his views were unusually advanced for a medieval scientist, and in spite of the errors which they undoubtedly contain, the insight of their author cannot fail to compel respect. Thus, 'heaviness is the force with which a heavy body is moved towards the centre of the world' and 'a heavy body is one which is moved by an inherent force, constantly, towards the centre of the world' [Lecture I, Chap. I, Sect. 1]. Further, 'That point in any heavy body which coincides with the centre of the world, when the body is at rest at that centre, is called the centre of gravity of that body' [Lecture I, Chap. I, Sect. 4]. The Aristotelian hypothesis on motion, however, died hard: 'Bodies alike in gravity are those which, when they move in a liquid from some single point, move alike—I mean, pass over equal spaces in equal times' [Lecture I, Chap. I, Sect. 4]. Again, 'the weight of any heavy body, of known weight at a particular distance from the centre of the world, varies according to the variation of its distance there-

from; so that, as often as it is removed from the centre, it becomes heavier, and when brought nearer to it, is lighter ...' [Lecture I, Chap. V, Sect. 3]. Such statements as the last two remind us that we are not yet in the realm of modern science, for in the latter case Al-Khāzīnī had in mind the fact that as the atmosphere became rarer, the upthrust exerted by displaced air would be reduced. In fact he assumed that air has weight, although he attempted no measurements.

The Arabs widely exploited natural sources of power, windmills and water-mills (figure 2) being constructed where climate and geography permitted [5]. Thus, according to Mustaufī, '10 leagues to the north of this city (Nishapur) is a mountain from which flows a river which causes several mills to turn with great speed', while Marrākeshī states that 'there are in the city (of Marrakesh) and even under the surrounding walls, some three hundred water-mills'. In Afghanistan, where the winds blew without cessation, carrying great clouds of sand, nature's tremendous forces were recognized and harnessed. Al-Mas'ūdī (c. 947) [6] referred to the value of the windmill, as did Al-Istakhri a little later; and a full description was given by Al-Dimashqī in the thirteenth century: 'The inhabitants use the wind for turning the mills and for the removal of sand from one place to another. They erect a high building like a minaret; or they use a high summit of a mountain or a similar prominence or a tower of a castle, and upon this raise up a building. In the building is a mill which revolves and grinds, while below is a toothed wheel which is caused to rotate by the useful action of the wind. The wheel rotates below, thereby driving the mill above'. Windmills were also used to raise water from wells in order to irrigate the gardens. Whereas water-mills are mentioned in Vitruvius, Book X, Chap. 10, and were perhaps invented in the time of Augustus, it seems likely that the windmill was an Islamic application of later date. The latter was certainly referred to by Al-Mas'ūdī as though its use were commonly accepted in Afghanistan. It is possible that the windmill was known in Arabia as early as the first half of the seventh century A.D.

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Vitamin B₁₂

A. W. JOHNSON and SIR ALEXANDER TODD

The successful isolation and identification of the anti-pernicious-anaemia factor, vitamin B₁₂, has been the outcome of a combined effort by biologists, chemists, and crystallographers. Beginning at the recognition in 1926 of the therapeutic value of liver in the treatment of pernicious anaemia, the main features of the story of vitamin B₁₂ are here described up to the announcement of the total structure in 1955. This structure strongly suggests that the vitamin is related to haem, chlorophyll, and other natural porphyrin derivatives.

In an important paper published in 1926, G. R. Minot and W. P. Murphy [1] reported that whole liver was effective in the dietary treatment of pernicious anaemia. From that time onwards many groups of chemists and biochemists subjected liver extracts to chemical fractionation in attempts to isolate the active principle, but it was not until 1948 that the pure anti-pernicious-anaemia (APA) factor, now known as vitamin B₁₂, was isolated independently and almost simultaneously by K. Folkers and his colleagues [6] in the laboratories of Merck and Company Inc. in America and by E. Lester Smith and his associates [3, 5] of Glaxo Laboratories Limited in England. The early work, which resulted in several commercial preparations of liver concentrate appearing on the market, has been summarized by Y. Subba Row, A. B. Hastings, and M. Elkin [2], who emphasize the diversity of the views held at different times on the nature of the anti-pernicious-anaemia factor. During the period up to 1945 covered by their review, the amount of material needed per day by a patient suffering from the disease decreased from 400 grams to less than one milligram as concentrates improved in quality, and the authors stated that the isolation and identification of the active material might reasonably be expected to be an attainable object. Many early workers in the field held the view that the factor was protein or polypeptide in nature, although later the opinion was expressed by some that it might be a compound related to the pterins, a group of substances which had been shown to occur in the wings of a variety of insects. The discovery of the folic acid group of vitamins at first seemed to support this view, but liver concentrates were eventually prepared which were effective in smaller doses than pure folic acid in the types of anaemia for which this substance had activity.

Probably the main reason for the long period which elapsed before the factor was finally isolated

was the lack of a rapid and reliable method of bioassay; no animal test was discovered giving results parallel to those of clinical studies in man. Indeed, in their final isolation procedure the British workers [3] used clinical assay almost exclusively for testing concentrates. The American group, however, utilized an important observation by M. S. Shorb [4] that the anti-pernicious anaemia factor of liver is also a highly active growth-factor for the organism *Lactobacillus lactis* Dorner, and they were able to develop a microbiological method of assay. Microbiological methods are now used almost universally for assay purposes, although other micro-organisms are now recommended, such as, among others, *L. leichmannii* 4797 or 313. When finally isolated as a deep red crystalline solid, and tested for activity in the clinical treatment of pernicious anaemia, positive responses were obtained with the vitamin in a dosage of 0.5–5 micrograms daily. Vitamin B₁₂ is thus one of the most potent of all physiologically active compounds. As has happened in the case of other vitamins, it was soon found that, in addition to the vitamin B₁₂ isolated from liver, there appeared to be quite a number of very closely related substances in nature having varying degrees of activity. It is, in fact, appropriate to think of vitamin B₁₂ as multiple in character; to this point we shall return later. The difficulties of the isolation of the vitamin from liver led to searches for other sources, and soon workers in the Merck laboratories [7] reported that it could be isolated from culture broths of *Streptomyces griseus*, the strain used for the production of streptomycin. Later work showed that members of the vitamin B₁₂ group of compounds were present as by-products in the waste liquors resulting from the production of a number of other antibiotics, such as neomycin and chloromycetin, but today it is more usual to employ a special fermentation for the production of the vitamin; *Bacillus megatherium* and *S. olivaceus*

have been recommended as particularly suitable organisms for this purpose. The idea that the vitamin normally has a microbiological origin has received further support from the discovery that appreciable quantities of it and related compounds are present in sewage sludge. Sewage sludge has indeed been considered as a possible starting material for commercial production of vitamin B₁₂, although the separation of the closely related substances present in it might prove to be costly and time-consuming. Seaweed also is rich in the vitamin, although here again it has been shown that it is synthesized by micro-organisms and merely concentrated by the algae. The extraction of vitamin B₁₂ from these various sources, where it occurs in extremely low concentrations, is a multi-stage procedure generally involving solvent extraction, adsorption, and chromatography. The extensive use of such solvents as phenol and benzyl alcohol has been a noteworthy feature of the large-scale isolation methods.

A great deal of research has been carried out to determine the biological functions of vitamin B₁₂, and although much remains to be done several apparently unrelated biochemical problems have already converged on this new member of the vitamin B group. One of these problems concerns the so-called animal protein factor. The fact that animal protein contains a growth factor which is not present in vegetable protein has been recognized for some time, but the problem was revived during the last war, when the scarcity of animal protein caused the introduction of a higher proportion of soya bean meal into poultry feeds. The unknown factor was shown to be present in cow manure and also in poultry droppings after, but not before, incubation, thus suggesting that the factor was formed through the intervention of micro-organisms. American workers in the Lederle Laboratories [8] were the first to demonstrate that the anti-pernicious-anaemia factor of liver was the main component of the animal protein factor when they produced concentrates from bacterial cultures obtained from hen faeces which were active in both senses. The growth-promoting properties of crystalline vitamin B₁₂ for rats and chicks was originally described in 1948, but it has since been demonstrated that less of the vitamin is required in the presence of certain antibiotics, e.g. aureomycin and penicillin. Concentrates of vitamin B₁₂ are very widely used today as feed supplements for pigs and poultry, only a few milligrams being required per ton of foodstuff. Although many of the ambitious claims for certain therapeutic appli-

cations of the vitamin should be treated with reserve, all the early successes in the treatment of pernicious anaemia have been fully confirmed. An interesting consequence of one aspect of this work has been the elucidation of the relation of vitamin B₁₂ to the anti-anaemia factors of W. B. Castle [9], who had shown that there was a thermostable substance, the extrinsic factor, present in certain foods, which produced a response in pernicious anaemia patients only when administered with normal gastric juice; the latter was said to contain the intrinsic factor. The extrinsic factor is now known to be identical with vitamin B₁₂, and the intrinsic factor is a protein recently claimed [10] to have been prepared in a very concentrated form. There is as yet no evidence for a chemical reaction between vitamin B₁₂ and the intrinsic factor, which seems to differ from the so-called B₁₂-binding proteins which have also been purified. Apart from its anti-anaemic and nutritional functions, vitamin B₁₂ plays an important role in the reduction of disulphide groups and in the biosynthesis of labile methyl groups, e.g. in the biosynthesis of methionine from homocystine and of choline from glycine, although probably it does not participate directly in transmethylation.

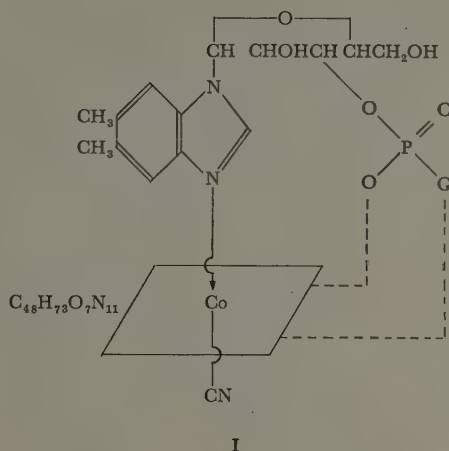
Vitamin B₁₂ crystallizes from aqueous acetone or hot water as beautiful dark-red hydrated crystals with the formidable molecular formula C₆₃H₉₀O₁₄N₁₄PCo. A unique feature of the molecule is the presence in it of a cobalt atom, and magnetic measurements indicate that the cobalt is in the trivalent state; no cobalt-containing organic compounds other than members of the B₁₂ group have yet been found in nature. The vitamin as isolated is a weak base, and its characteristic ultra-violet and visible absorption spectra are not greatly affected by changes in pH. Very soon after the isolation of vitamin B₁₂ it became apparent that a number of closely related substances existed, all possessing comparable biological activity, and their inter-relation became clear when vitamin B₁₂ was found to contain a cyanide group directly attached to the cobalt atom. The cyanide group was detected both by its chemical and its physical behaviour, and it could be replaced without difficulty by any one of a variety of other groupings. For example, substitution of the cyanide by hydroxyl gave rise to vitamin B_{12a} (or B_{12b}), and substitution by nitrite gave vitamin B_{12c}. These compounds can be reconverted to vitamin B₁₂ by treatment with cyanide ions. In order to simplify the nomenclature, vitamin B₁₂ is now officially designated cyanocobalamin; B_{12a}

is hydroxocobalamin; B_{12c} is nitritocobalamin; and several other members of the group have been described. They can be distinguished by their chromatographic behaviour and by their partition coefficients in various solvent mixtures.

Further knowledge of the chemical structure of the vitamin came from studies of its acid hydrolysis. This phase of the work was carried out on very limited amounts of material, and considerable use was made of chromatography on paper for the examination of microquantities of reaction products. When the vitamin was heated with concentrated hydrochloric acid at 150° for several hours there were produced, in addition to ammonia (five to six molecules per molecule of vitamin) and phosphoric acid, a red cobalt-containing resin and two further products which were detected by paper chromatography. The first of these was a base which gave a blue coloration with ninhydrin and which eventually proved to be Dg-1-amino-2-propanol (one molecule per molecule of vitamin). The other compound, also a base, was detected by its fluorescence in ultra-violet light and proved to be 5:6-dimethylbenzimidazole. Less drastic hydrolysis of the vitamin gave two N-substituted 5:6-dimethylbenzimidazoles, designated the α - and β -components respectively. Further hydrolysis of the α -component gave first the β -compound and then 5:6-dimethylbenzimidazole itself. All three of these degradation products have been isolated, and their structures have been determined and confirmed by synthesis. The β -compound is the N- α -D-ribofuranoside of 5:6-dimethylbenzimidazole and the α -component is the corresponding 3'-phosphate, so that the α - and β -components can be regarded as benzimidazole analogues of the purine nucleotides and nucleosides. It is of some interest to note, however, that these benzimidazole glycosides have the α -configuration, whereas the natural purine nucleosides are uniformly β -glycosides.

The addition of excess cyanide to vitamin B₁₂ causes the formation of a purple complex containing two cyanide groups, and a careful examination of the ultra-violet absorption spectrum of this compound suggested that in the parent vitamin system is connected to the cobalt atom by a coordinate bond. The evidence presented so far, which was accumulated by K. Folkers and his colleagues in the laboratories of Merck and Company Inc.; by A. R. Todd, A. W. Johnson, and their co-workers at Cambridge; by V. A. Petrow and his group at British Drug Houses Limited,

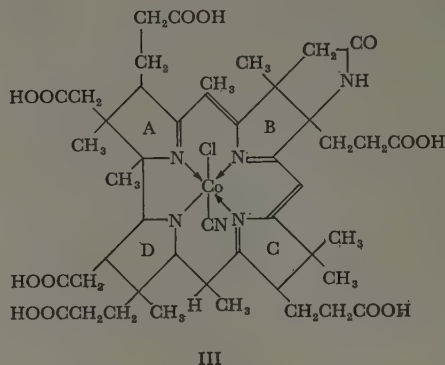
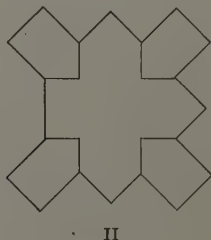
and by E. R. Holiday at the Medical Research Council Spectroscopy Unit, lead to the partial structure (I) for the vitamin.



Investigations of other microbiological sources of vitamin B₁₂ led to the discovery of a second group of related compounds isolated from fermentation liquors, sewage sludge, etc., which differed from vitamin B₁₂ in that they did not contain 5:6-dimethylbenzimidazole as the basic component of the nucleotide. Natural members of the B₁₂ group in which 5:6-dimethylbenzimidazole has been replaced by adenine, 2-methyladenine, and 2-methylhypoxanthine have been described, and other bases have been introduced into the molecule by microbiological synthesis in the presence of appropriate precursors. In general, these compounds have low animal activity and varying activity as growth factors for microorganisms. Apart from the nucleotide, the remainder of the vitamin B₁₂ molecule, the so-called Factor B, is common to all these compounds, and indeed Factor B itself has been isolated from fermentation liquors and from calf manure as well as from the products of brief hydrolyses of vitamin B₁₂ with warm acids.

The ammonia which is liberated during hydrolyses of the vitamin is now known to be derived from primary amides, and chemical evidence has been presented to show that there are certainly four, and probably six, primary amide groupings in vitamin B₁₂. In addition, the aminopropanol is bound amide-wise through the nitrogen atom, so that there are potentially seven carboxyl groups present in the central cobalt-containing portion of the molecule. In fact, the red resinous product obtained upon hydrolysing the vitamin is an

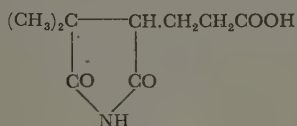
acidic mixture, the complexity of which was not fully appreciated until the technique of electrophoresis on paper was applied [11]. Two series of acids were then recognized, one lacking the nucleotide and containing from one to seven carboxyl groups (i.e. derived from Factor B), and the other retaining the nucleotide and containing one to six carboxyl groups. Further complications were caused by the large number of possible isomers; for example, three monocarboxylic acids containing the combined nucleotide were isolated in substance. These, as well as a number of di- and tricarboxylic acids of this series, were isolated and each could be re-converted to vitamin B₁₂ by re-forming the amides from the acids by orthodox methods. However, for further structural investigations it was desirable to prepare, in a pure crystalline state, one of the acids lacking the nucleotide. For this purpose the mixture of penta- and hexacarboxylic acids obtained from a hydrolysis of the vitamin with 30 per cent aqueous sodium hydroxide at 150° was selected. Separation of these acids on a relatively large scale was achieved by application of anion-exchange chromatography, and a pure hexacarboxylic acid, obtained as its monochloride-monocyanide, was eventually induced to crystallize [12]. This was the first crystalline degradation product, not containing the combined nucleotide, to be prepared from vitamin B₁₂. It had a molecular formula C₄₆H₆₀O₁₃N₆CoCl₂H₂O and possessed a visible spectrum very similar to that of the parent vitamin, indicating that the chromophore had not undergone any marked change. The crystalline acid was submitted to Dr D. C. Hodgkin at Oxford for crystallographic examination, and she and her colleagues were able to construct the general pattern of the nucleus (II) surrounding the cobalt atom [13]. This pattern was identical with that already found by Dr Hodgkin in the molecule of vitamin B₁₂ itself and provided welcome confirmation of this novel macrocyclic ring system which, although reminiscent of that found in the natural porphyrins, differed strikingly in that two of the four



rings present were joined together directly rather than by way of an intermediate carbon atom.

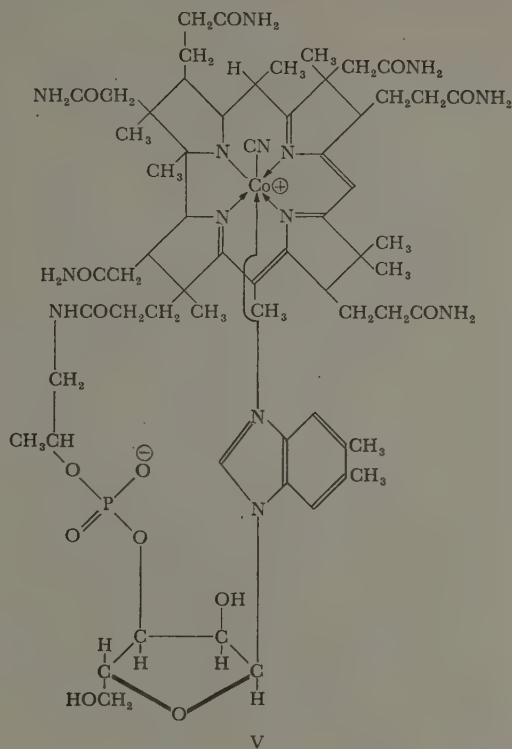
Soon afterwards the relative positions of all the atoms, excluding hydrogen, were deduced by a brilliant piece of X-ray analysis by Dr Hodgkin and her colleagues, and, taking into account the known chemical properties of the compound, structure (III) was deduced [14]. Of the six acidic groups, four were present as propionic acid residues and the other two as acetic acid residues, all of them being attached to the β -positions of the five-membered rings. The additional five-membered ring fused to ring B of the central nucleus was formulated as a lactam because of its stability to alkali. The eight single-atom side chains were all formulated as methyl groups to conform to the chemical analysis, assuming that some of the oxygen in the crystalline material was present as water of crystallization, as found in the crystal structure. The double-bond arrangement, formulated as shown on the basis of X-ray and chemical evidence, is still tentative and may be the subject of slight revision. Independent chemical evidence supporting the structure of ring C as formulated in (III) was provided by the isolation of the succinimide (IV) from oxidations of a crude vitamin B₁₂ hydrolysate by the Merck group of workers [15]; the production of the same product from the pure hexacarboxylic acid was later confirmed at Cambridge. Once structure (III) had been established, the electron density patterns for crystals of vitamin B₁₂ itself became easier to interpret. It appeared from these patterns that the vitamin did not contain a five-membered lactam ring fused to ring B but that, instead, this ring bore in one β -position a methyl and an acetamide residue and in the other a propionamide residue. Also, the cyanide in the vitamin was attached at the side of the cobalt atom opposite to that of the cyanide group in the hexacarboxylic

acid. The aminopropanol was attached to the propionic acid side-chain of ring D and the phosphate was substituted only by the nucleoside and by the aminopropanol, as had already been deduced from the stability of the phosphate linkage. Accordingly the molecule was formulated as a zwitterion, the negative charge of the phosphoric acid being balanced by a net positive charge on the cobalt atom. With these additional facts it is possible to derive the complete structure (V) of vitamin B₁₂, although the precise location of the double-bond system, assigned largely on the basis of the behaviour of the vitamin on chlorination experiments, is still in some doubt. Further work is necessary to clarify this point, which does not, however, affect the main structural picture.



IV

It would seem more than coincidence that the arrangement of propionic and acetic acid side-chains in (V) corresponds to that of uroporphyrin III, for which a biogenetic scheme has been demonstrated [16]. A modification of this scheme [14] has been suggested which could give rise to the nucleus of vitamin B₁₂, and at the same time it suggests methods by which synthetic approaches to this complex molecule might be formulated.



V

Viewed in the light of this suggestion, the extraordinary complexity of the vitamin B₁₂ molecule is somewhat mitigated, since it can be regarded as a not too distant relative of the natural porphyrin derivatives such as haem and chlorophyll, which are found widely in nature.

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Shock waves in air

E. W. E. ROGERS

The shock waves which develop when gases move at speeds greater than that of sound have assumed great importance in the design of aircraft, and they have been intensively studied both experimentally and theoretically. They are also significant in other connections; thus they offer a means for studying the behaviour of gases at temperatures otherwise unattainable in the laboratory. The main properties of shock waves and their significance are here reviewed.

The unexpectedly large resistance of the air to the passage of a body moving faster than the speed of sound seems to have been noticed first during gunnery trials with spherical shot in 1742. Nearly 150 years were to elapse, however, before it was realized that the increased resistance was due to the formation of intense compression waves in the air near the body. The scientific study of these compression waves (now called shock waves) has made such progress during the present century that when the first controlled flight at supersonic speeds in a piloted aircraft took place in 1947 (only forty-four years after the Wright brothers made the first flight in a heavier-than-air machine) the behaviour of the aircraft was similar to that predicted from laboratory tests.

Shock waves are characteristic of gas motion at supersonic speeds, and cannot arise when the motion is everywhere at a speed lower than that of sound. Since a sound wave can be regarded as an infinitely weak shock wave, the velocity of sound is a convenient standard with which to compare the velocity of a shock wave. In the simple theory for the propagation of a sound wave it is generally assumed that the accompanying changes of the air density and pressure are very small and that the form of the wave is unaltered with time. When the amplitude of the pressure disturbance is no longer small, however, the wave may change in form as the disturbance progresses [1], the high-pressure region of the wave travelling more quickly than that having a lower pressure. Eventually the low-pressure region is overtaken, and the pressure rise then occurs almost discontinuously through a very steep 'front'; the disturbance has become a shock wave (figure 1).

The shock wave advances into the undisturbed air at a velocity greater than that of a sound wave, but because of the temperature increase accompanying the pressure rise, the velocity of the shock relative to the air left behind it is below the speed

of sound for that region. The opposite type of wave, in which the pressure decreases through a very steep front, can never be formed; such a wave would be unstable and would rapidly change in form.

The pressure discontinuity possible in wave motion was first considered by Stokes in 1848, and subsequent investigations during the nineteenth century added to the knowledge of what was regarded as an interesting phenomenon, even if of only academic significance. By 1910, however, when the subject was very fully discussed by Rayleigh [2], knowledge of the production of shock waves by high-speed projectiles and by explosions was firmly established, and in subsequent years research increased as the importance of shock waves in the aerodynamics of aircraft, missiles, and rotating machinery, in detonation problems, and in combustion thermodynamics became apparent.

Shock waves behave differently from some other types of waves, such as sound, light, and electromagnetic waves. For example, the excess pressures caused by interfering sound waves are additive; the interaction and reflection of shock waves, on the other hand, can lead to very large pressure increases [3]. This difference in behaviour is due to the non-linear form of the differential equation governing the formation and propagation of shock waves, a form which makes the mathematical analysis rather complex.

For the practical problems in which shock waves occur it is usually sufficient to regard them as simple discontinuities in the characteristics of a

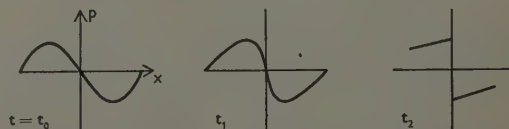


FIGURE 1—Formation of a pressure discontinuity in a large-amplitude pressure wave propagating in a perfect gas.

perfect fluid. In a real fluid, such as air, the steepening of the pressure front with progression of the wave (figure 1) is resisted by the diffusive action of viscosity and heat conduction, and as a result the pressure gradient in the fully developed compression wave remains finite, though large. The shock wave then has a definite thickness and structure, and this has been much studied in recent years, both from the viewpoint of the kinetic theory of gases and from that of a continuous fluid. This work is referred to briefly later.

SHOCK WAVES IN STEADY AIR FLOWS

To an observer moving with the shock wave the air appears to approach the wave at a supersonic velocity and to recede from it with a velocity less than that of sound for the region to the rear of the wave. A shock wave which is inclined to an approaching supersonic air stream behaves similarly to the velocity component normal to the wave front but leaves unaltered the velocity component along the front. Thus an inclined shock wave reduces the resultant flow velocity of the stream by some amount, usually leaving it still supersonic, and in addition turns the flow abruptly through an angle. Thus the sudden deflection of a supersonic stream by a solid boundary will be accomplished in regions away from the boundary by an inclined shock wave of the appropriate inclination and strength (figure 2). A subsonic stream approaching the corner would change direction gradually with none of the sudden alteration of direction and velocity characteristic of supersonic flow.

Since shock waves caused by the high-speed flight of bodies are of considerable practical importance, it is of interest to see how these arise. For convenience the body will be considered as

stationary in a moving air stream; because it causes a disturbance in this stream, the air is both accelerated and retarded in the neighbourhood of the body. At one particular subsonic value of the stream speed the velocity of sound will be reached at some position on the model surface, and a further increase in stream speed then causes a local supersonic flow region to occur adjacent to the model. While the air can be accelerated smoothly to supersonic speeds by the body's curved surfaces, the subsequent retardation back to subsonic conditions is inherently unstable and is accomplished instead by means of a normal shock wave; this wave marks, therefore, the rear end of a local supersonic flow embedded in the subsonic stream.

As the stream speed approaches that of sound the normal shock wave moves back to the rear of the body, and when the stream speed is just supersonic a bow shock wave appears in the stream ahead. This bow wave renders the flow between it and the body subsonic, and can therefore be regarded as the limit to which the pressure disturbances caused by the model can be transmitted upstream. With a further increase in stream speed the bow wave approaches the body and the intermediate subsonic region diminishes. If the nose of the body is sharp, the bow shock wave subsequently attaches to it and is then inclined at the appropriate angle for deflecting the flow past the model in a way similar to that shown in figure 2. Further increases in the stream speed merely reduce the angle between the shock waves and the direction of the undisturbed flow, and at very high supersonic speeds the bow wave will lie close to the body surface. This complete sequence of shock wave growth and movement is depicted diagrammatically in figure 3.¹

When the flow round the body has regions of both subsonic and supersonic flow, the position and strength of the shock waves are very difficult to predict theoretically if only the body shape and the stream speed are given. This mixed type of flow occurs in the so-called transonic region when the stream speed is near that of sound. For aircraft this speed range is of great importance, and information about shock wave effects and the

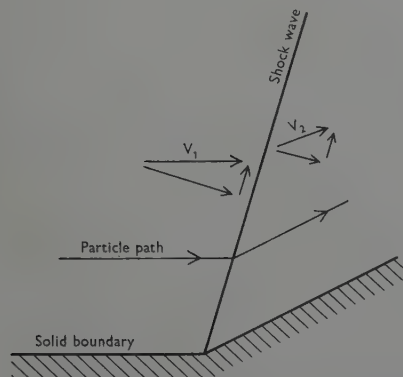


FIGURE 2 - Deflection of flow by a shock wave.

¹ The similarity between wave patterns shown in figure 3 at supersonic speeds and the surface wave pattern caused by a ship when this is viewed from above is not entirely fortuitous. The motion of a free water surface when the water depth is very shallow is in fact equivalent to the wave motion caused by a similar disturbance in a gas if the ratio of the specific heats of the gas is 2; for air the ratio is 1.4.

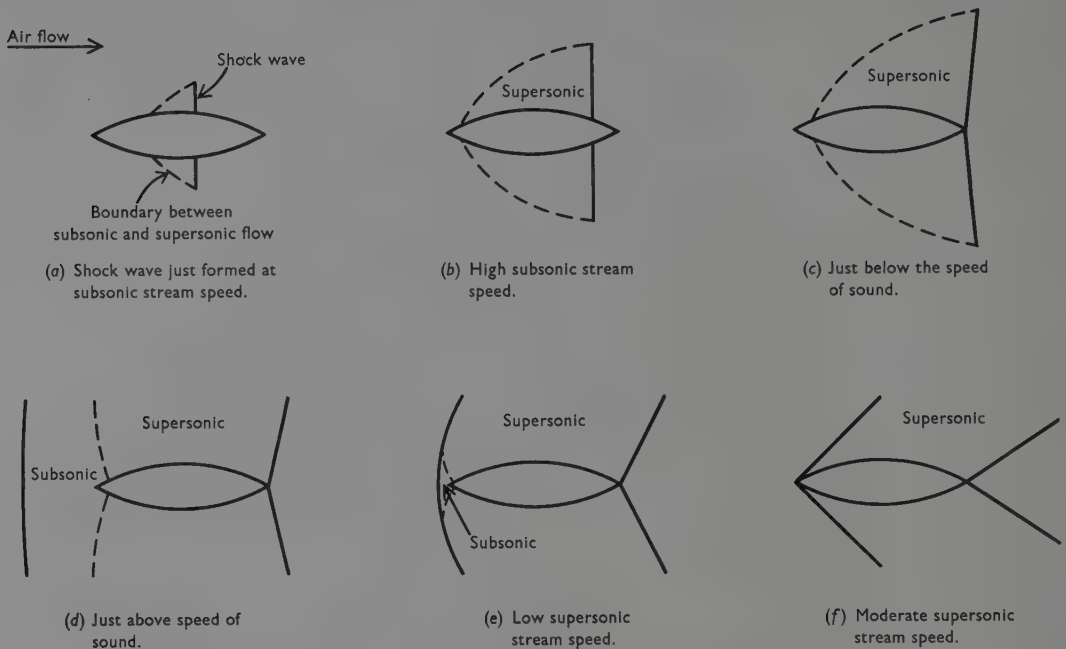


FIGURE 3 — Diagrams of shock-wave growth and movement for a typical body immersed in a steady air stream.

resulting behaviour of a body at such speeds is usually obtained experimentally either from models in free flight or from stationary models held in the air stream of a wind tunnel. The latter arrangement has many obvious advantages.

For a wholly supersonic flow field the mathematical analysis is rather easier, and in recent years much progress has been made in predicting the position and strength of the expected shock waves. The theoretical results have been largely substantiated by experimental data, obtained from both free-flight and wind-tunnel tests.

The free-flight technique is widely used by ballisticians. As early as 1886 Ernst Mach [4, 5] obtained a photograph of a bullet in flight at about 1.5 times the speed of sound; this clearly showed the inclined shock waves originating from the nose of the bullet, a flow pattern which Mach had expected on theoretical grounds. Because of his pioneer work in studying the problems of high-speed flight, the ratio of the model velocity (or alternatively the fluid velocity if the model is stationary relative to the observer) to the local speed of sound is usually called the Mach number of the motion, designated by M . Figure 6 shows a modern photograph of a projectile in flight at a Mach number of 2.51. The shock waves, being

regions of intense density gradients, refract the light issuing from a short-duration spark and hence appear as shadows (with adjacent bright bands) on a photographic plate placed on the far side of the projectile from the spark. The width of these shock-wave shadows depends mainly on the geometry of the apparatus and is not related to the actual shock-wave thickness; this remark, it should be noted, applies to all the flow photographs shown in this article.

In the wind tunnel a uniform air stream is created and made to flow past a stationary model at speeds up to about nine times that of sound; the shock pattern caused by the model can then be studied visually or by means of suitable exploring gear. This is usually a far more convenient method for obtaining information than by means of a model in flight, and is very widely used.

The working section of the wind tunnel where the model is placed may vary in size, from tunnel to tunnel, from a few square inches in cross-section to many square feet; the corresponding model size will also vary, and for the larger tunnel the model may be several feet in span and length, thus allowing considerable detail to be represented if this is required. Large, modern high-speed wind tunnels are complex pieces of equipment, perhaps

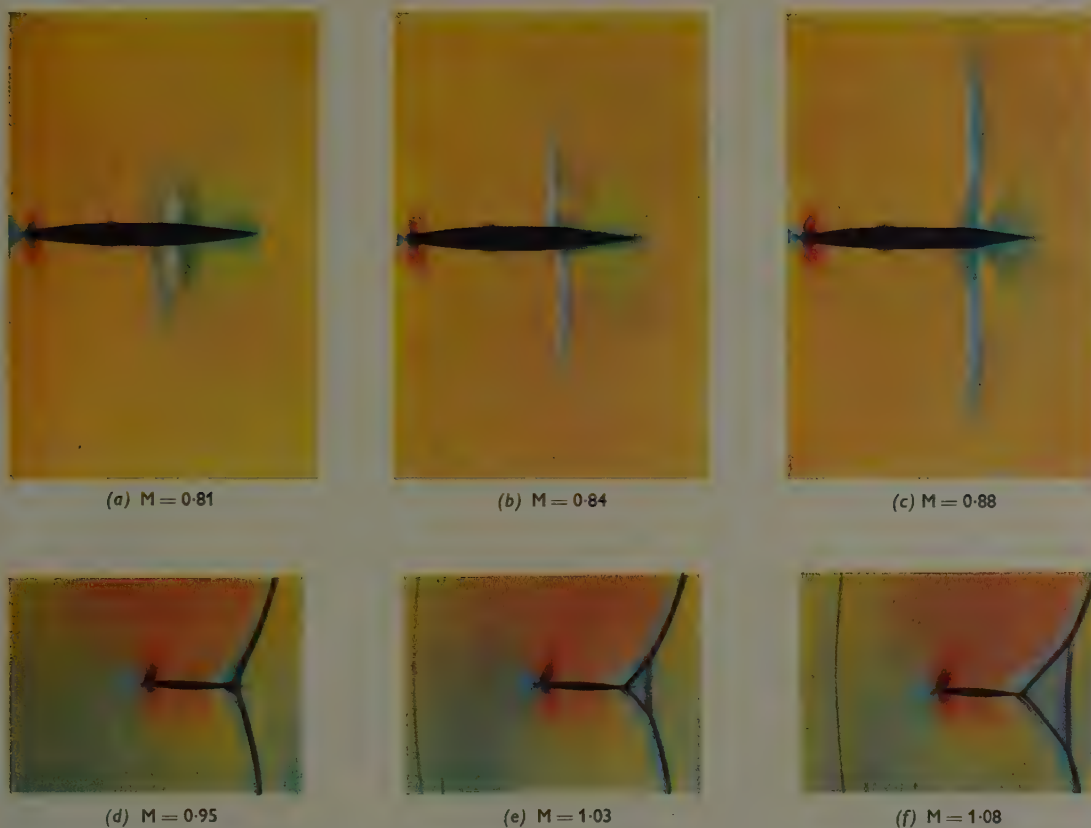


FIGURE 4 (a) to (f) – Colour Schlieren photographs of flow around model wing section at subsonic and transonic Mach numbers. (Air flow from left to right.)

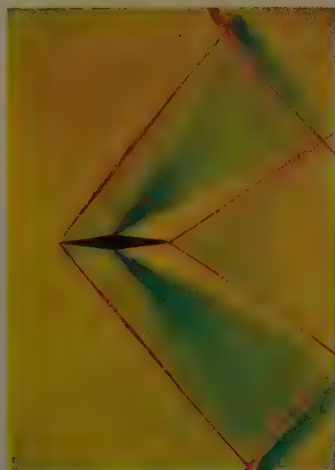


FIGURE 5 – Colour Schlieren photograph of flow round typical supersonic wing section at $M = 1.6$. (Air flow from left to right.)

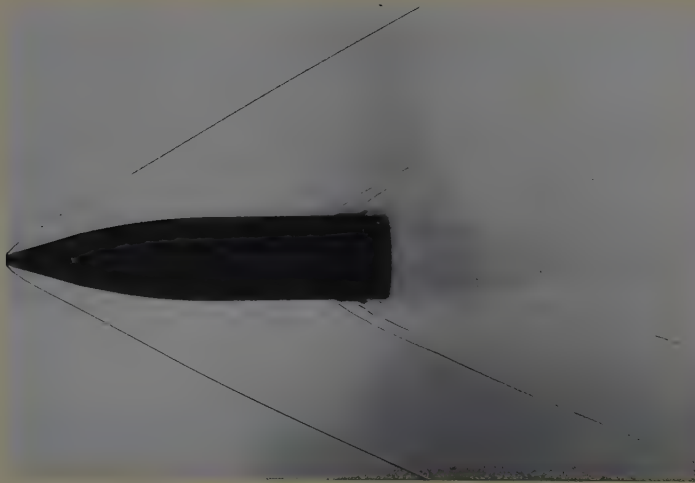
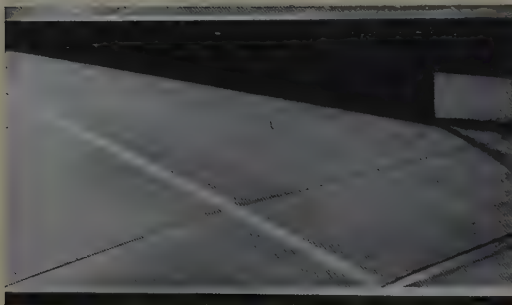
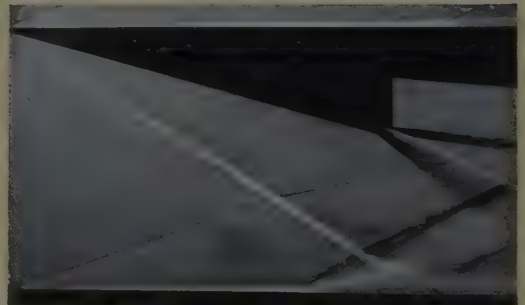


FIGURE 6 - *Shadow photograph of projectile in flight at $M = 2.51$.*



(a)



(b)

FIGURE 7 - *Reflection of shock waves from flat plate at $M = 3$, showing different types of interaction between the shock wave and the plate boundary layer (Schlieren photographs; air flow from left to right). (a) Reflection of weak shock. (b) Reflection of strong shock.*

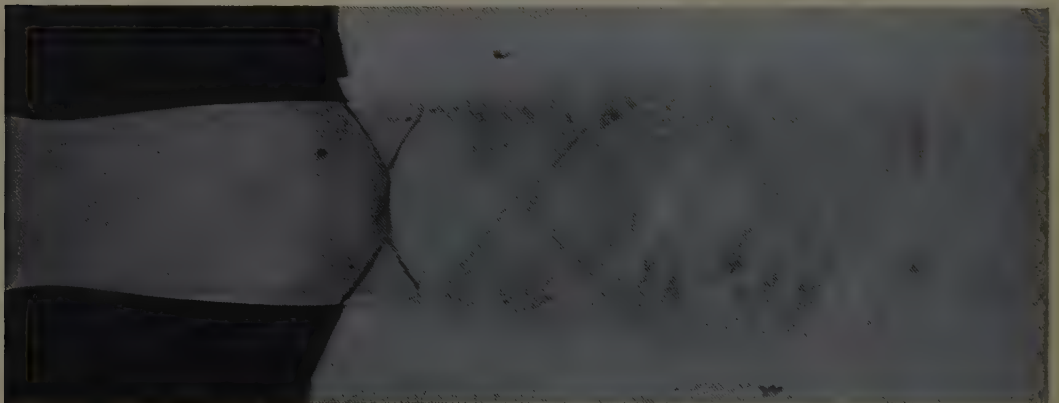


FIGURE 8 - *Shock waves in air jet issuing at $M = 1.43$ (Schlieren photograph).*

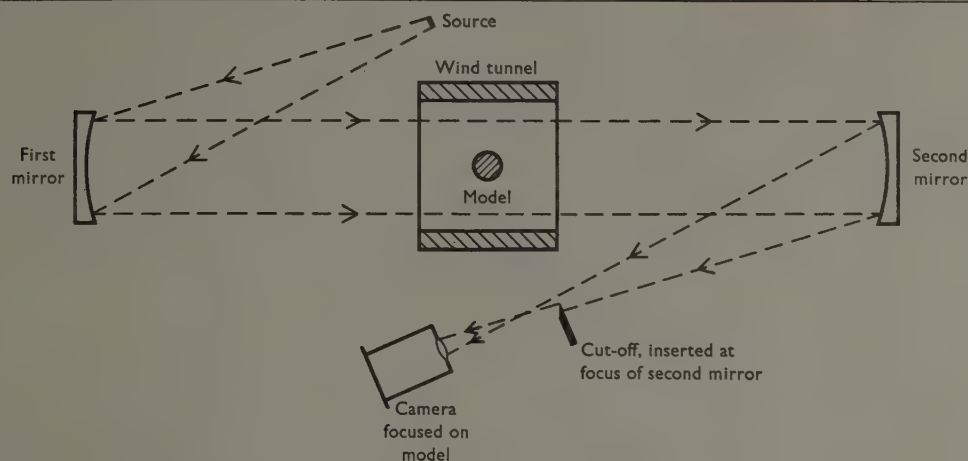


FIGURE 9 – Schlieren optical method as used for wind tunnel. (Flow in tunnel normal to plane of paper.)

costing millions of pounds to build and requiring several thousands of horse-power to provide the air stream. The air is driven past the model either by some form of fan or axial air compressor or by compressed air injected at high speed through narrow slots in the tunnel wall downstream from the model position. Such tunnels can usually be run either continuously or for long enough for the finite duration of the run to be unimportant. For achieving Mach numbers of above about 4 in the working section it is often more convenient to exhaust a high-pressure air receiver to atmosphere through the working section or to fill an evacuated vessel from the atmosphere, the working section being placed on the inlet pipe to the vessel. The duration of the run with these types of tunnel is small, often only a few seconds, and care must be taken with the instrumentation in order to obtain accurate information in this limited time.

As the air is accelerated into the working section of the tunnel its temperature is reduced, and this reduction is sufficient to cause condensation of the oxygen and nitrogen present in the air when the Mach number in the working section is above about 4.5 unless the slow-moving air awaiting entry to the working section is heated well above the normal atmospheric temperature.

The shock waves from the model in the tunnel air stream can be demonstrated optically in a manner similar to that used for the photograph of the projectile in figure 6. Alternatively, interferometers, usually of the Mach-Zehnder type, can be used to give the density field around the model; the air density can also be measured directly by determining the absorption of X-rays passed

through the flow in the tunnel at the model position. The most important method, however, is that adapted by Mach from its original use by Toepler for investigating imperfections in optical mirrors. Because of this origin it is known as the *Schlieren* (or, more rarely, the striation) method [6]. The optical arrangement usually employed for wind tunnels is shown in figure 9; the light, refracted by changes in the fluid density near the model, is deflected either on to or away from the cut-off inserted at the focus of the second mirror. The direction of the deflection depends on the sign of the particular density gradient causing the optical disturbance, and the changes in illumination in the image of the flow field obtained in the camera are proportional to these density gradients.

With a monochromatic light source the shock waves appear as either light or dark bands on a grey background. Alternatively, a small spectrum can be used as a light source, and the refraction effects can then be made to give colour changes on either side of the position in the spectrum of the background colour. This colour *Schlieren* method [7] was used to obtain figures 4 and 5. In figure 4 the model represents an aircraft wing section and completely spans the width of the wind tunnel, so that the flow does not vary across this width. The sequence of photographs shows the growth and development of the shock waves as the Mach number of the approaching air stream is increased, and thus corresponds to part of the flow changes sketched in figure 3. The shock waves in figure 4 (a), (b), (c) appear blue (i.e. they cause a displacement to the blue side of the background colour), and regions where the density decreases in the

stream direction show up as red. The second sequence of photographs on this figure ((*d*), (*e*), (*f*)) illustrate the air flow around the same wing section at speeds close to that of sound; the background colour, however, has been chosen from a different part of the spectrum. In figure 5 the wing section is of a different shape and has the sharp leading edge necessary for allowing the bow wave to attach to the model at the Mach number of the flow (1.6). The optical system for this photograph was set up so that the colour changes obtained are the reverse of those shown in figure 4; thus the red shock waves can be clearly seen, as well as the green continuous expansion zone, shaped like a fan, which is caused by the air expanding around the shoulder of the section.

Shock waves similar to those shown in figure 5 would arise from the wing of an aircraft flying faster than sound, and in certain conditions can sometimes reach the ground, even though the aircraft itself may be manoeuvring at an altitude of more than 20 000 ft. These shock waves can then be heard by an observer on the ground as sharp reports, which are generally referred to as 'sonic bangs'. Often two or more of these bangs are heard in rapid succession, and at present there is some doubt as to the true cause of these multiple bangs. They may be due to the separate shock waves associated with the wing and tail of the aircraft, or alternatively they may arise from a single wave which has become distorted during its descent to the ground and as a result of its reflection from the ground. It now seems to be agreed that the bang is due to the disturbance of the air caused by the moving aircraft and that the accumulation of noise from the engines adds only a small amount to the pressure wave that is finally heard by the observer. The intensity of the pressure-wave depends on the position and flight path of the aircraft but it can be sufficiently strong to break windows locally on the ground.

The reflection of the bow shock wave from the tunnel wall can be seen in figure 5. In theory the reflected wave should be a simple compression wave, but the green zone near the point of reflection indicates that an expansion of the flow is taking place as well. The more complex nature of the reflection is caused by the narrow band of air adjacent to the tunnel wall which has been slowed down by friction effects (the wall boundary layer). The interaction between a shock wave and the boundary layer of a surface near by is of great importance and has been much studied in recent years [8]. Figures 7 (*a*) and (*b*) show respectively

the interaction of a weak and a strong inclined shock (caused by the wedge at the top of the picture) with the boundary layer on a flat plate. In the second case the interaction is severe enough to cause the flow to separate from the surface of the plate upstream from the point of interaction. The refraction of a weak inclined shock wave (passing upwards from left to right) through the stronger shock, and also through an expansion fan at the rear end of the wedge, should be noticed in figure 7 (*b*).

The surface pressures in the interaction region change with the type of interaction, and can seriously modify the resultant force of the air stream on the body. If the interaction takes place near an aircraft control surface (aileron or elevator) it can cause the control to become ineffective, with perhaps disastrous results for the aircraft. The solution of this type of problem can come only from intensive wind-tunnel tests on model controls.

Another aspect of high-speed flow involving shock waves is the discharge of gas from an orifice. Figure 8 shows an air jet issuing at a Mach number of 1.43. The initial well-defined shock-wave system adjusts the pressure within the jet to that of the surrounding air, but the subsequent mixing at the jet boundary causes the jet to break up, the velocity of the air being reduced by a succession of shocks.

SPHERICAL SHOCK WAVES

Explosion waves in air can be regarded as spherical shock waves travelling outward from the site of the explosion. In such a motion the velocity is radial and, unlike the steady air flows previously discussed, the characteristics of the wave front depend on its distance from the origin and on the time that has elapsed since the explosion took place. From a knowledge of the mass of explosive used to generate the wave, the total energy available for the motion can at once be defined. The strength of the spherical shock wave (initially much stronger probably than would be encountered in high-speed flight) decreases with time, and the air which has been compressed by the passage of the shock wave is subsequently able to expand to a pressure which may be below that existing ahead of the wave. This suction phase is an important feature of wave motions caused by explosions. G. I. Taylor has discussed the problems of blast waves in some detail in [9], and has compared his theoretical results with experimental observations made during the explosion of the first atomic bomb in New Mexico in 1945.

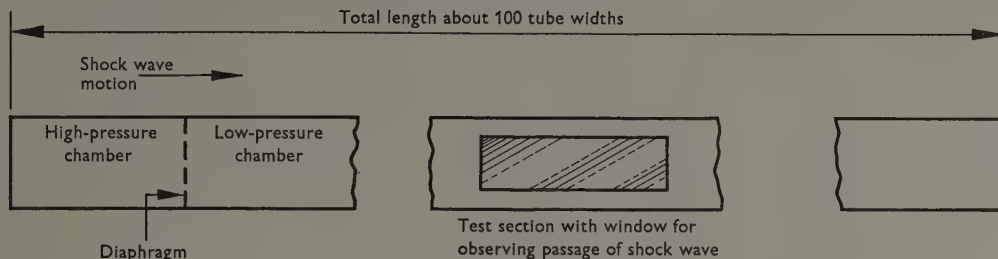


FIGURE 10—Diagram of shock tube.

STRONG SHOCK WAVES AND SHOCK STRUCTURE

The great strength of the shock waves caused by an explosion implies that the temperature reached by the air behind the wave will be very high; in such conditions the air can no longer be expected to behave like a perfect fluid, and for this reason the study of the behaviour of strong shock waves is of considerable interest.

One method of investigating intense shock waves in the laboratory is by means of the shock tube [10] (figure 10). This consists essentially of a long uniform tube about 30 cm square, divided initially by a diaphragm into two compartments containing gas—usually air—at different pressures. When the diaphragm is ruptured, a normal shock wave moves into the low-pressure part of the tube and an expansion zone into the high-pressure region. The transient interaction of this shock wave with solid objects placed within the tube can then be studied; for example in [11]

photoelastic methods were used to determine the transient internal stresses of the model.

The departures of the shock-wave behaviour from that predicted by assuming the perfect gas laws are mainly due to the variation of the specific heats with temperature and to gas dissociation and ionization, the last two effects becoming important at temperatures above about 3000° K and 5000° K respectively. Figure 11 shows the magnitude of the temperature reduction caused by these three effects as a function of the Mach number at which the shock propagates.

For large temperatures and low densities behind the shock, the time taken for the molecules of the gas to reach equilibrium after passing through the shock becomes important. The degrees of freedom associated with the molecular translation and rotation require only a few collisions to obtain thermal equilibrium, but molecular vibration and dissociation require a much larger number of intermolecular collisions for equilibrium to be established. These two modes are negligibly small at moderate densities, and the thickness of the resulting shock, the region within which the gas state is altered, is of the order of a few mean free paths. The strong shock in rarefied gases probably consists of two parts, a steep front only a few mean free paths thick, followed by a zone of greater length in which thermal equilibrium is reached between the translational and rotational degrees of freedom on the one hand and the vibrational and dissociation modes on the other.

These molecular effects occur in some gases at much less extreme conditions than is the case for air, and by a judicious choice of the working fluid information relevant to the behaviour

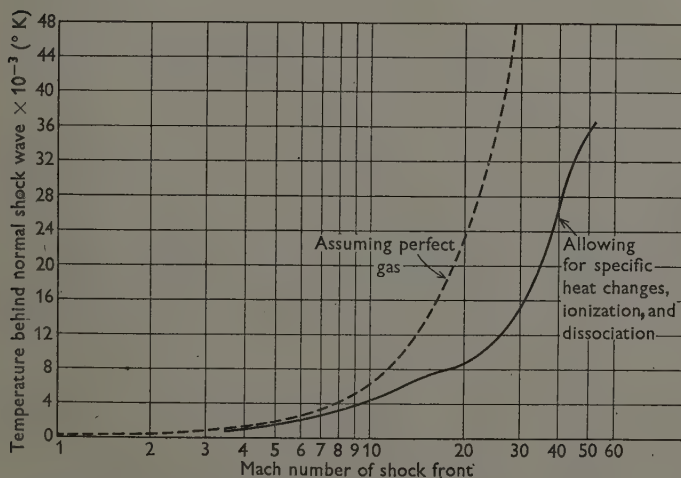


FIGURE 11—Theoretical temperatures reached behind strong shock waves advancing into undisturbed air at 300° K.

of air at very high Mach numbers and low densities can be obtained in a rather easier fashion.

A strong shock wave produced in a shock tube can alternatively be regarded as a means of producing very high temperatures within a gas. In such cases the temperature to the rear of the shock can be increased by the reflection of the shock from the closed end of the shock tube, or, in a modified form of tube, by causing the shock wave to become cylindrical and to converge towards a point. Usually a single gas and not a gas mixture is studied, and temperatures up to 18 000° K have been obtained by these means [12]. At these high temperatures the shock becomes highly conducting electrically, and a band of luminosity, thought to be due to dust particles, develops behind the shock. Spectrographic studies of the shock front have also been made.

Apart from its intrinsic interest, information of this type is valuable to those studying meteors, since these can be regarded as projectiles travelling at high Mach numbers (up to say 100) in a low-density atmosphere [13], causing a strong but diffuse shock wave; not a great deal of information on this aspect of shock waves has yet been published. The problem is complicated because an allowance must be made for the evaporation of the meteor due to the high temperature behind the shock wave. It is perhaps relevant to note that, on a much larger scale, phenomena similar to diffuse shock waves are thought to occur in the rarefied gas clouds of interstellar space.

The structure of the shock wave can be investigated theoretically, either by assuming a continuous, but viscous and heat-conducting, gas or by using the kinetic theory of gases. The assumption of a continuous gas is satisfactory only for Mach numbers below about 2. At higher Mach numbers the kinetic theory of gases has generally been used, allowance being made in this way for the changes in heat conduction and viscosity coefficients with temperature. The analysis for gases like air which are not composed of single molecules is very complex [14], and simplifying assumptions often have to be made before a solution can be obtained.

Except for very low density flows, any attempt to measure the shock thickness by direct exploration methods must fail because of the very small distances involved. An elegant technique has been developed [15], however, which is based on the fact that the shock-wave thickness is about equal to the wavelength of light. The reflection of a beam of light from the front of a shock wave advancing in a shock tube can be analysed and the results compared with those predicted from theoretical models of the shock structure. The reflected light pulse is only about one-millionth of the incident light in intensity, and its duration about 20 microseconds. So far only shock fronts in argon and nitrogen at low supersonic shock speeds have been measured by this method; for these gases it was found that the theoretical shock models were not greatly in error.

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The mycorrhiza of forest trees

J. L. HARLEY

Although the fact that the roots of certain plants are commonly associated with fungi has long been known, the significance of this association has only comparatively recently become apparent. Experimental evidence indicates, however, that in the case of forest trees these root-fungal associations act as highly efficient aerobic accumulators of ions, assisting both plant and fungi in their competition for nutrients with other living organisms in the soil.

It has been known for more than a hundred years that many higher plants live in a close association with fungal mycelia which exist on or in the tissues of their roots. The activities of some of these fungi cause considerable changes in the morphology and anatomy of the roots, with the result that composite fungus-root structures, conspicuously different from uninfected roots, are formed. Changes resulting from the activities of other fungi may be externally invisible but nevertheless significant. The name mycorrhiza was first applied to fungus-roots of the first type by A. B. Frank [3], who made a detailed study of the roots of the European beech. He showed that similar mycorrhizas were present on the roots of many angiosperm trees belonging to the Cupuliferae and on the roots of the pines and related plants. Later the name mycorrhiza was extended to all those associations of fungi with the absorbing organs of green plants and of higher plant saprophytes, such as the colourless orchids, in which clear structural or histological changes result from fungal infection of normal healthy individuals in their natural habitats. At some stage in their life, or in some habitats, the majority of root systems and other underground absorbing organs of plants have now been shown to form mycorrhizal organs falling within the above definition.

Quite early in the study of mycorrhizas the opinion was formed that mycorrhizal infection in some way stimulated the growth of the plants which possessed them, and it was natural that the early hypotheses concerning their physiological functioning should associate them particularly with nitrogen absorption. The nitrogen-fixing role of the bacterial nodules on the roots of legumes had already been proved, and many agricultural experiments on the treatment of soils with manures had appeared to show that nitrogenous substances were of overwhelming importance in plant growth. The assumption, without rigorous

experimental proof, of a stimulating effect of mycorrhizal infection, and its explanation in terms of nitrogen supply, combined with the lack of knowledge of the physiology of absorption of mineral substances by plant roots, has been in large measure responsible for the slowness with which an understanding of mycorrhizal phenomena has been reached. Another important factor which contributed to confusion of thought, was the tendency to assume that all kinds of fungus-root associations, which had been called mycorrhizas, were physiologically similar in spite of great structural diversity. To obviate this last difficulty only one type of mycorrhiza will be discussed in detail in this article; it should be realized that the results of the researches here described must not be applied to other kinds of mycorrhiza without very careful consideration of their own peculiar properties.

The ultimate rootlets of many of the trees most common in European and other temperate forests—such as beech, sweet chestnut, the birches, oaks, and hazel among the angiosperms, and the pines, spruces, and larches among the conifers—are all associated with fungi under natural woodland conditions. The structures of the mycorrhizas formed by them are very similar in all important respects. The rootlets, which are somewhat thick and blunt-ended, form closely aggregated racemose systems of branches, or more rarely, as in the pines, are repeatedly forked. Mycorrhizal roots of the beech growing in their natural surroundings are shown in figure 4 and their anatomical structure is illustrated in figure 5. The host tissue is completely surrounded by a tissue of fungal hyphae so closely knit into a false cellular structure, especially in the outer region, that interhyphal spaces are hardly discernible. The central core of host tissue is penetrated in its outer cortex by fungal hyphae which grow between the cells, within the thickness of the cell-walls, to form a

network called, after the German plant pathologist who first described it, the Hartig net. Some hyphae penetrate into the lumina of the cells, but such penetration is variable in amount and may be almost completely absent. Hyphae in variable numbers also pass outwards from the fungal sheath into the soil. Some of the main branches of these root-systems, however, as well as some of the minor laterals, seem to remain uninfected for a great part of their life, and they show a more normal root structure, with root-caps and root hairs.

The detailed structural differences, and differences in histology and mode of growth, between infected and uninfected roots have been described in detail for some species, and a start has been made in explaining the differences in terms of auxin production by the fungi, but a discussion of this aspect of mycorrhizas cannot be attempted here. Many of the roots that long remain uninfected do become infected during some stage of their lives. Sometimes, as in the beech, they become overgrown by a complete fungal sheath which develops behind the rapidly growing apex of the root; during periods of stagnation in root growth in summer this sheath may actually close over the apex. In other cases, for instance in pine, an internal infection of the tissues follows differentiation of the cells behind the apex of the long roots.

The fungi concerned in the formation of tree mycorrhizas have been studied in detail by E. Melin [7, 8, 9, 10] and his associates in Sweden [11]. The most profitable method of identifying them has proved to be the culturing of mycelia from the commonest fruit bodies found in the vicinity of the host trees in their natural habitat, and testing of the ability of these to form mycorrhizas by inoculating them on to the roots of sterile seedlings. It has been demonstrated that a great number of toadstools belonging to the Agaricaceae and Boletaceae, and some puff balls, such as *Scleroderma*, form mycorrhizas. In all cases the physiological properties of the species are somewhat unusual. They show an inability to develop in culture on sources of carbon more complex than simple carbohydrates, and they frequently need supplies of accessory factors, such as the vitamins thiamin and biotin, for satisfactory development. They therefore contrast with other humus- and wood-inhabiting fungi of the same taxonomic groups which have powers of breaking down lignin and cellulose and which may be readily grown in culture. These cultural characteristics, together with a conspicuous lack of ability to compete in

mixed culture with unspecialized soil saprophytes, link them physiologically more closely with specialized parasites than with litter- and humus-decaying forms. There is considerable evidence that many species are unable to produce fruit bodies in the absence of their host trees.

The intensity of mycorrhizal development upon any host plant varies with the conditions of its habitat. External factors seem to influence the development of mycorrhizal structures through their effects upon the host plant rather than directly upon the fungi. The earliest workers observed that the most intense development of infection occurred on humic soils where layers of partly decayed plant remains persisted as a permanent horizon on the soil surface. In this horizon an aggregation of mycorrhizal rootlets could be seen growing in close competition with large quantities of mycelia of very varied types. After periods of leaf fall there may be a temporary release of considerable quantities of plant nutrients into these humus horizons, but they are rapidly absorbed by the living components of the layer and the average content of available nutrients throughout the year is very low. In soils in which humus layers do not accumulate, and where the supply of available nutrients is permanently held at a higher level, mycorrhizal development is much less conspicuous.

The experimental results of A. B. Hatch [5] in America, later greatly extended by E. Björkman [1] in Sweden, have gone far to explain this variation. It appears that in any given light intensity in which growth is possible, mycorrhizal development increases with increasing deficit of plant nutrients, notably nitrogen and phosphorus and possibly also potassium. The higher the light intensity the higher is the content of available nutrients which will allow a given development of mycorrhiza. These relationships hold, of course, only within what may be called the working ranges of nutrient concentration and light intensity, and do not apply to conditions of acute starvation nor of great excess of nutrient, nor when the light is very intense, and they often require some modification to allow for the effects of interaction of the nutrients. The conclusion was therefore reached by Björkman, and confirmed by analysis, that infection depends upon the presence of excess carbohydrate in the root tissues. Since Björkman's important conclusion was published many other observations have been shown to agree well with his hypothesis. For example, the initial infection of seedlings after

germination in both pines and beech does not occur until after the foliage leaves are expanded, when free carbohydrates are present in the root tissue. It is attractive, yet dangerous, to connect the demand for simple carbohydrates by the fungi in culture with these observations and to regard this as an instance of cause and effect. Other fungi, which are unable to form mycorrhiza, have similar demands for simple carbohydrates.

The relatively great development of mycorrhizas in soils deficient in nutrients led the earliest observers to a teleological interpretation of mycorrhizal function which survives till the present. Crudely stated, the argument was that the great development of mycorrhizal roots in soils low in nutrients proved that their function was to increase mineral absorption. Whatever the properties of mycorrhizal roots may be, this argument is quite valueless. Three kinds of ecological and experimental evidence are available respecting their functions as absorbing organs which are quite free from the taint of this error. First, attempts to establish trees, especially coniferous trees, in localities not natural to them have often failed, especially when plantings were done on humic soils; correlated with the failures were failures in mycorrhizal development. Various soil treatments, such as those performed by M. C. Rayner at Warham [12], have resulted in both a more satisfactory growth of the young plants and a development of mycorrhizas on their roots. To see these changes as examples of cause and effect would be rash without further evidence. Secondly, experimental inoculation of seedlings with mycorrhizal fungi, to compare their growth with that of uninoculated seedlings, has been attempted many times. Experiments of this kind, so simple in concept, are technically difficult to carry out, but the few fairly satisfactory ones show that on nutrient-deficient soils an increase in weight, coupled with a disproportionately large increase of nutrient absorption, occurs in the mycorrhizal seedlings. One example is given in table I, which summarizes results obtained by Hatch with *Pinus strobus*.

It has been assumed, following Hatch, that this increased mineral absorption in mycorrhizal seedlings results from the greater surface area in mycorrhizal root systems as compared with uninfected systems. The dangers in this suggestion lie first in the impossibility of finding a method whereby the root-surface areas can be compared with reasonable accuracy, and secondly in the implication that a root system surrounded by a fungal sheath has properties, in terms of absorp-

TABLE I

	Dry weight	Nitrogen (% dry wt.)	Phosphate (% dry wt.)	Potassium (% dry wt.)
Mycorrhizal seedlings	404.6	1.24	0.20	0.74
Non-mycorrhizal seedlings	320.7	0.85	0.08	0.43

Results of A. B. Hatch, 1937 [5].

tion of minerals per unit area, similar to those of uninfected roots. Such a view was tenable only while nutrients were believed to enter by mass movement in the transpiration stream or by the physical process of diffusion. Now that salt absorption has been shown to depend on metabolic reactions, some modification of this hypothesis becomes necessary. From the very structure of mycorrhizal roots it follows that all materials that enter the host must pass in some way through the fungal tissue of the sheath, and that their mode of entry, as well as the form and quantity in which they enter, are likely to be different in infected and uninfected roots.

In recent years experimental evidence of a third kind has been obtained by treating mycorrhizal roots as single functional organs rather than as a compound of two separate organisms lying side by side. The techniques used have often been exactly those used in the study of salt uptake by normal roots.

Melin and his associates [8, 9, 10] have elegantly demonstrated that the out-growing hyphae from the mycorrhizal sheath are capable of functioning analogously to root hairs. Pine seedlings were grown in sterile sand cultures in such a way that open culture dishes of mycorrhizal fungi could later be placed on the surface of the sand. In the course of time the hyphae from the cultures grew over the lips of their dish through the sand and formed mycorrhiza on the pine rootlets. By inserting isotopically labelled solutions of phosphate, nitrogen compounds, and metallic nutrients in the fungal cultures, the movement of these solutions to the roots and into the organs of the host plant could be followed.

Information concerning the rates of absorption, and the effect of external factors on these rates, has been gained using excised mycorrhizas of pine and beech in experiments of short duration. The rates of absorption by uninfected roots and infected roots, on an area or weight basis, have

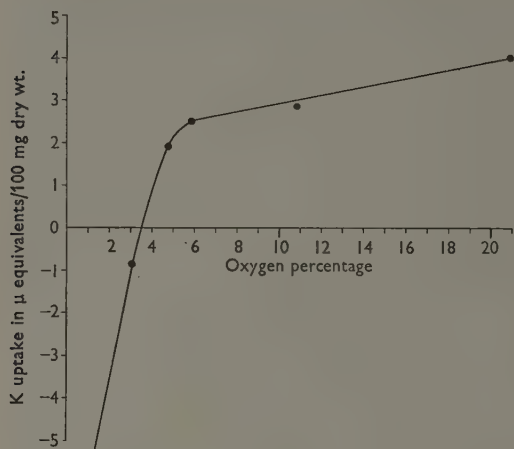


FIGURE 1—The effect of oxygen concentration upon the absorption of potassium from a solution of KCl (0.128 mM) during 17 hours by beech mycorrhizas.

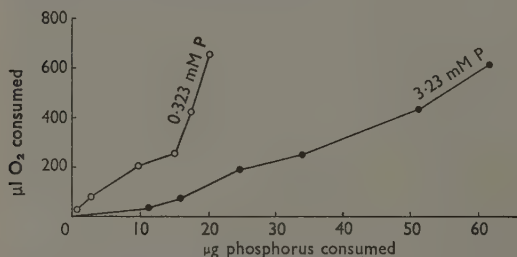


FIGURE 2—Relationship between oxygen consumed and phosphate absorbed, at two different concentrations, by beech roots.

been compared in pine by P. J. Kramer and K. M. Wilbur [6] and in beech by J. L. Harley and his colleagues [4]. In each case a greater quantity was absorbed by infected roots; in the case of beech, for instance, phosphate was absorbed about five times, and potassium about twice, as rapidly. The rates of absorption by beech were particularly sensitive to oxygen supply, and the process of salt accumulation in the tissues is indirectly linked with respiration.

Figure 1 shows that potassium absorption occurs only at oxygen concentration above 3 per cent by volume, and reaches its maximum at between 10 and 20 per cent. Figure 2 shows the kind of relationship between oxygen consumption in respiration and phosphate absorption.

Mycorrhizal roots are similar to uninfected roots in the dependence of their absorption rate upon temperature, concentration of salt in the external solution, and the presence of substances inhibitory to metabolic processes. Both show the

property of selective absorption, such as a preferential absorption of potassium from a mixed solution of alkali metals (table II).

TABLE II

Solution	K uptake		Na uptake	
	μE/ 100 mg	% of Control	μE/ 100 mg	% of Control
0.1 mM KCl ..	1.68	100	—	—
0.1 mM NaCl ..	—	—	0.41	100
0.1 mM NaCl + 0.1 mM KCl	1.37	82	0.06	14

Results of J. M. Wilson (unpublished).

This kind of result emphasizes the ability of mycorrhizas to accumulate salts as other absorbing organs do; although in some respects they differ greatly in experimental behaviour, their efficiency in salt accumulation cannot be doubted.

One important effect of the fungal sheath complicates this simple view of them as highly efficient salt-absorbing organs. A detailed examination of the immediate distribution of salts absorbed by mycorrhizal roots shows that the primary accumulation is not uniform, but that a large proportion of the salt absorbed is retained in the fungal sheath. This is particularly evident in phosphate absorption, where as much as 90 per cent of the absorbed ion is retained by the sheath in experiments of short duration, using the kinds of concentration likely to be present in soil solution. The release of accumulated phosphate to the whole system has been shown to be a gradual process, dependent upon temperature and oxygen supply (figure 3). It occurs only in oxygen concentrations

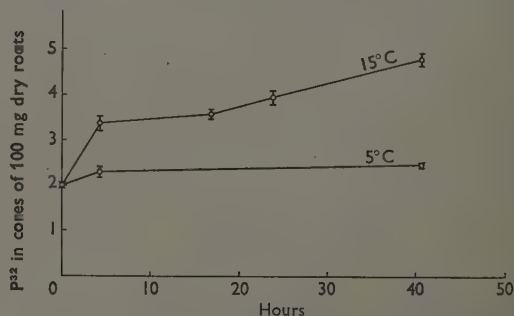


FIGURE 3—Movement of phosphate from the fungal sheath into the host tissue of beech mycorrhizas kept in phosphate-free solutions at 5° C and 15° C.

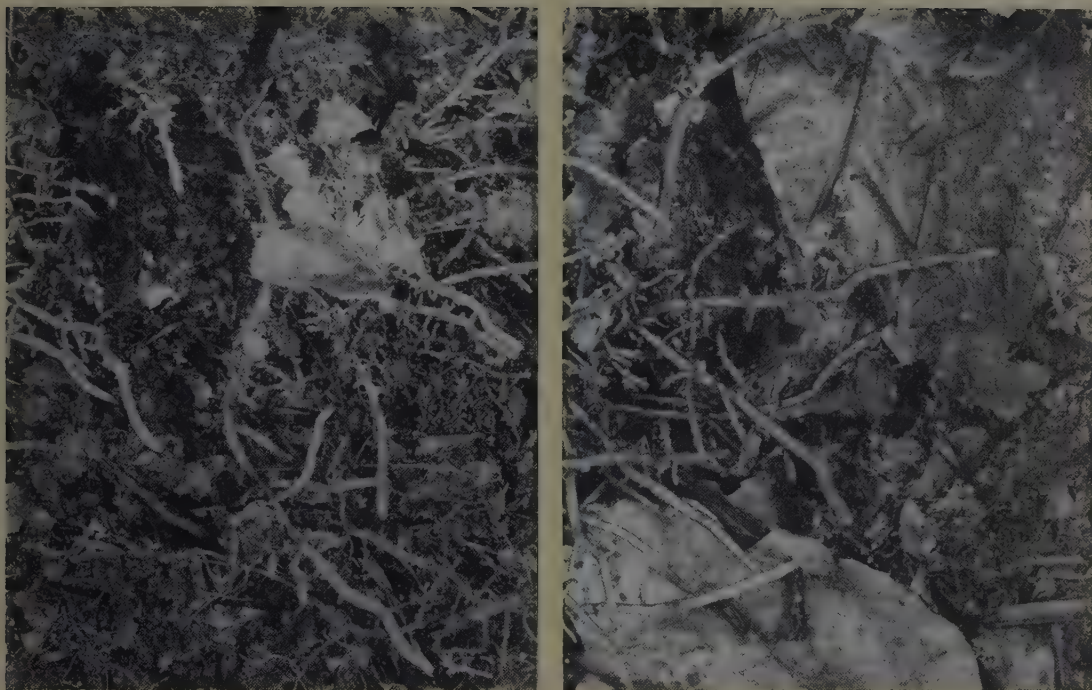


FIGURE 4 – Photographs of mycorrhizal roots of beech in the humus layer of the soil. (Slightly enlarged.)

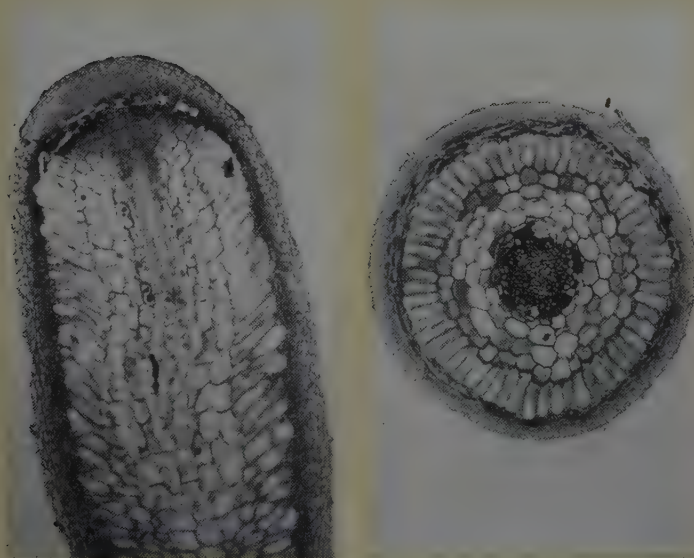


FIGURE 5 – Sections of mycorrhizal roots of beech, showing the sheath of fungal tissue enclosing the host tissue. The hyphae of the Hartig net may be seen between the cells of the cortex. ($\times 130$ approx.)

(Photograph by F. A. L. Clowes)



FIGURE 6 – Longitudinal section of an uninfected beech root for comparison. ($\times 200$ approx.)

(Photograph by F. A. L. Clowes)

of above 3 per cent by volume, and it is most rapid in air when phosphate is absent from the external solution.

This experimental work on the rate of salt absorption has emphasized the aerobic nature of the processes of initial uptake and of redistribution. It has been explained that the uppermost humus layers of the forest floor are the natural site of the greatest development of mycorrhizas: consequently it is necessary to know the state of oxygen supply in these layers in order to apply the experimental results to natural conditions with any reliability. Estimates by J. K. Brierley [2] of the soil atmosphere in the zones of intense development of beech mycorrhiza have demonstrated no lack of oxygen. Throughout a whole season the oxygen concentration by volume remained above 19 per cent in all cases tested. One can therefore accept the view that mycorrhizal roots are highly efficient aerobic accumulators of ions, so that in times of litter breakdown they successfully compete for plant nutrients with other living organisms of the humus zones of forest soils. The material so accumulated may become available to both host and fungus by a gradual but metabolically dependent process of redistribution.

This recent experimental work has provided an adequate explanation of the many observations on the success of mycorrhizal plants in poor soil under both natural and experimental conditions, and has at last brought the study of mycorrhiza out of a

phase where magical properties seemed to be ascribed to mycorrhizal organs. It is as absurd to assume that the development of mycorrhizas with the formation of the fungal sheath about the roots has no effect upon absorption as it is to suggest that forest tree seedlings cannot be grown without mycorrhizas. The seeds of forest trees will germinate and develop into seedlings in sand or water culture in conditions where no mycorrhizal organs are formed. Indeed, plants in heavily manured soils may grow exceedingly vigorously in a relatively uninfected state, but this is not their normal habitat nor their normal condition in their natural surroundings. Experiments in recent years, carried out under the aegis of the Forestry Commission, have aimed at determining whether it is necessary to raise nursery stocks of seedlings equipped with mycorrhizas for transplanting into forest soils, or whether seedlings heavily manured with inorganic fertilizers in their early life are successful as transplants, although initially non-mycorrhizal. Such results, when available, are likely to be highly important in shaping nursery policy, and they have already proved valuable in correcting far-fetched claims concerning the importance of mycorrhizas in development. The ecological and physiological experiments on mycorrhizas described in this paper are not concerned primarily, however, with these economic problems, but with the functioning of mycorrhizas as absorbing organs in forest conditions.

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Book reviews

CYBERNETICS

The Human use of Human Beings (revised edition), by Norbert Wiener. Pp. 199. Eyre and Spottiswoode (Publishers) Limited, London. 1954. 18s. net.

This book was first published in 1950, and the present is a revised edition. Cybernetics is now defined as the science of messages, of their communication, and of the control which their communi-

cation can effect. Since society, apparently, is nothing at all but a form, or forms, of communication, it seems as if the science of messages ought to be able to explain all social phenomena. Professor Wiener believes that it can do this, but the fact is that the real interest of this book does not lie in his application of certain excessively generalized, familiar principles of cybernetics to

social problems, but in his own brilliantly expressed and uninhibited reflections about many questions of contemporary interest. Among these are the processes by which human beings learn to know or to do things; the history, development, and use of language; legal problems in society, with special reference to views about punishment; and science and secrecy. Wiener

displays an enormous fund of knowledge and an enviable certitude of expression. The critical reader may agree or disagree with some or all of what he says about these matters, and still legitimately remain convinced or unconvinced about the claims made for cybernetics as a social science.

F. C. BARTLETT

SCIENCE AND RELIGION

Science and Religion: A Changing Relationship, by C. A. Coulson. (The Rede Lecture for 1954.) Pp. 36. Cambridge University Press, London. 1955. 2s. 6d. net.

In this lecture Professor Coulson's aim is to describe the change in the relationship between science and religion which has been brought about by the progress of science. He deals with two aspects of this change, which he associates with nature and with man, but he points out that they overlap considerably.

Professor Coulson definitely rejects a modern tendency to divide nature into two parts in which science and religion have their respective fields of application, nor will he accept the view that God is to be found in the regions of thought into which science has not yet penetrated. Either God is in the whole of nature or He is not there at all; equally, the whole of nature is open to scientific treatment. The old objectivity of nature, however, is no longer tenable. It must be recognized that 'our intellect does not draw its laws from nature, but imposes its laws on nature'. In this respect the scientist is at one with the artist, the poet, and the saint; on the other hand, in the recent advances of science he is increasingly separated from them by the growing remoteness from ordinary experience of the most fundamental scientific conceptions.

Professor Coulson calls attention to man's displacement from the central position which he formerly occupied in the universe, to his insignificance in metrical terms, and to the fact that the nature in which he is involved is now without a centre for him to occupy—or, alternatively, every point in it is a centre. Such a universe can be regarded as 'somehow holding God', as a painting does, 'and God is, as it were, the canvas on which the painting depends'. But man, as well as being inseparably involved in this God-inhabited universe, is in another sense the author of it, since 'there is a definite

sense in which nature itself . . . is a construct of man'. This complicated relationship between man and nature is quite different from the old view, in which man stood outside a completely objective nature and tried to describe it mathematically. The author concludes that with our greater knowledge, 'no satisfactory account of nature can be given except in personal terms'.

The lecture is very thought-provoking, and may be expected to meet with either approval or dissent according to the views of the reader. One effect of the changing relationship is that those who are willing to accord equal validity to science and religion will differ widely among themselves as to the point of view from which the whole subject can best be surveyed, and they will find each other's pronouncements not so much unacceptable as inapt. In these circumstances it is a salutary discipline to try to discover the angle from which the inaptness disappears. Professor Coulson's treatment lends itself readily to such an effort, and those who make it are likely to be well rewarded.

HERBERT DINGLE

STOCHASTIC PROCESSES

An Introduction to Stochastic Processes, by M. S. Bartlett. Pp. xiv + 312. Cambridge University Press, London. 1955. 35s. net.

Whenever a physical or biological system can usefully be thought of as developing in time under the influence of the laws of probability, the appropriate mathematical model of the system will be based on a stochastic process. The state of the system at the epoch t will then be represented by a random variable depending on t as parameter. Systems of random variables involving several parameters or a single parameter not identified with the time are also called stochastic processes and can be important (e.g. in the theory of turbulence) but the single (time-) parameter occurs in the great majority of applications. The theory of stochastic processes has developed with remarkable speed during the last ten years, outstanding contributions to its methodology having been made by Professor Bartlett and his school, first in Cambridge and now in Manchester. Nothing could be more timely than this most original book, addressed quite frankly to the 'practical' man who wants ideas he can develop rather than theorems he can quote (the theorems are to come later, in a companion

volume by J. E. Moyal). Many readers of this book will be led to describe the phenomena in their own special field in a new and illuminating way. To others, and especially to those professionally concerned with the mathematics of Brownian motion, nearest-neighbour systems, queues, population growth, population genetics, epidemics and communication theory, the idea of a stochastic process will be already familiar, but the author's treatment of these problems will be worthy of their attention.

Of especial importance are the concluding chapters in which Professor Bartlett writes about the difficult problems of estimating the structural parameters in a stochastic model and testing the 'goodness' of the 'fit'. Here the classical statistical procedures are not available without modification, and a whole range of new problems of statistical inference present themselves.

D. G. KENDALL

ELEMENTARY MATHEMATICS

From Simple Numbers to the Calculus, by Egmont Colerus. Pp. xi + 255. William Heinemann Limited, London. 1955. 12s. 6d. net.

This is a translation from the original German, and it reads surprisingly well. It is in fact an admirable introduction to elementary algebra, trigonometry, and calculus. It is written in a most attractive style by one who has clearly given very much thought to the problem of expounding mathematics to his non-mathematical colleagues. Almost every difficulty is anticipated and dealt with adequately. The exposition is enlivened with a number of historical interludes and elucidated by means of numerous examples. The real attraction of the book is the way in which it proceeds from specific examples to general statements, and this enables the man or woman who is not a specialist in mathematics to gain some appreciation of its principles and methods.

G. TEMPLE

ASTRONOMY FOR AMATEURS

Amateur Astronomer's Handbook, by J. B. Sidgwick. Pp. 580. Faber and Faber Limited, London. 1955. 63s. net.

The many amateur astronomers who possess and use a telescope of their own will find this volume a storehouse of useful information on a great variety of subjects. It is not intended to be either a textbook or a practical manual of instructions. It is a reference volume

which will assist the observer to use his telescope intelligently and efficiently, and to maintain it in good adjustment. The subjects dealt with include the light grasp, resolution, magnification, size of field, and aberrations of telescopes; types of oculars and objectives; optical materials and their properties; silver, aluminium, and other films on reflecting surfaces; types of telescopes, mountings, and drives; adjustments and testing; the atmosphere and 'seeing' conditions; micrometers, spectroscopes, and photometers; the eye and its role in observation; the use of photography and the properties of the photographic plate; diaphragms, filters, and clocks.

The book contains many useful practical hints, and the large number of line diagrams, which are of commendable clarity, add to its value. A bibliography of some 600 references provides a guide whereby the reader can obtain further information on most of the subjects discussed. The book, which is unique of its kind, will be invaluable to the practising observer. The printing and paper are of high quality.

H. SPENCER JONES

Observational Astronomy for Amateurs, by J. B. Sidgwick. Pp. 358. Faber and Faber Limited, London. 1955. 50s. net.

Designed to meet the needs of the amateur observer who possesses a small telescope and who wishes to use it for systematic observing, this book will meet a long-felt want. The fields in which the amateur observer can make the most useful contributions are observations of the Sun, Moon, planets, asteroids, comets, meteors, aurorae, zodiacal light, and variable stars. Methods and techniques of observations in all these fields are described, with many practical instructions and hints. The data tabulated in the Nautical Almanac and in the Handbook of the British Astronomical Association are explained, and at the end of each section the principal numerical data are listed. Methods of recording the observations are described. With this book as a guide the beginner will avoid many pitfalls and will soon gain the confidence and experience that are needed for enabling him to make contributions of value in the particular field of observation that he selects. A very comprehensive bibliography is given at the end, arranged according to the various sections, which will enable the observer to extend his knowledge of his chosen field of work.

In certain fields of observation as-

tronomy must continue to depend considerably on the contributions of amateur observers. Careful study of this book by the amateur cannot fail to enhance the value of the observations that he makes.

H. SPENCER JONES

RADIO ASTRONOMY

Radio Astronomy, by J. W. Pawsey and R. N. Bracewell. Pp. x + 359. Clarendon Press, Oxford. 1955. 55s. net.

In the decade since the end of the last war, radio techniques have opened a new and exciting era in astronomy. The Radiophysics Laboratory of the C.S.I.R.O. in Sydney has played a leading role in these new advances, and in this book two distinguished members of its staff present a most valuable survey of the subject. Radio astronomy has grown up on the borderlines of astronomy, physics, and radio engineering, and any successful treatise on the subject must cater for a wide variety of interests. The authors have succeeded remarkably in their attempt to make this work intelligible to all concerned. It is, of course, inevitable that the writers' special interests and experience should receive most emphasis, and the third of the book devoted to solar radio emissions is outstanding in its thoroughness. At the same time it is somewhat disappointing to find that the account of galactic and extragalactic emissions is limited to a single chapter. The recent discoveries in this field of radio astronomy, including the spectral line from the neutral interstellar hydrogen gas, are of such significance that a more extensive treatment would have been justified. The study of thermal radio waves from the moon is covered in a short chapter, and the radio echo aspects of radio astronomy are very clearly dealt with in chapters on lunar echoes and meteors. The book will be indispensable to all workers and students in this subject, and no scientist reading this volume can fail to be excited by the remarkable developments of the last few years and the great potentialities for the future.

A. C. B. LOVELL

EARLY ELECTRICITY

The Development of the Concept of Electric Charge, by Duane Roller and Duane H. D. Roller. Pp. iv + 97. Harvard University Press, Cambridge, Mass. 1954. \$1.60 net.

This little book is one of the Harvard

'Case Histories in Experimental Science', a series edited by Dr J. B. Conant. It traces the history of work on the electric charge from the earliest observations on frictional electricity down to the experiments of Coulomb, whose beautiful series of measurements with the torsion balance (incidentally, it was not he but Michell who invented the first such balance) established his famous law and so gave precision to the concept of electric charge.

This study, on a subject that has been comparatively little handled, gives much evidence of careful and sympathetic scrutiny of the records concerned, and the policy of providing extensive quotations, as well as diagrams, from the original books and memoirs is an excellent one. The description of Hauksbee, to whose work some prominence is justly given, as 'almost illiterate' seems unduly severe, and is not supported by the extracts furnished—would that some of the literates of today would describe their experiments as simply and clearly as he did his in his 'Physico-Mechanical Experiments'. This difference of opinion is, of course, a trifle, as are one or two other differences noted. The only serious fault that can be found in this commendable book is the frequent omission of precise references for passages quoted and experiments described, which is the more regrettable because it diminishes its usefulness for the student of the history of physics, who will be well advised to keep a copy on his shelves.

E. N. DA C. ANDRADE

QUANTUM ELECTRODYNAMICS

Einführung in die Quantenelektrodynamik, by Walter Thirring. Pp. xii + 122. Franz Deuticke, Vienna. 1955. DM 17.50 net.

This book grew out of a series of seminar lectures on quantum electrodynamics given five years ago. It is to be hoped that Dr Thirring's example of making his lecture notes available in published form may be followed by other specialists.

The title may prove somewhat misleading. The reader is expected to be already familiar with the original form of quantum field theory. He will find here, elegantly and clearly condensed, an account of both formal and conceptual developments during recent years. The emphasis, however, falls on formalism and applications, perhaps an advantage for anyone who, being already acquainted with the subject, may

wish quickly to refresh his knowledge of technical points.

The book begins with a qualitative estimate of the orders of magnitude of the different physical effects which quantum electrodynamics is called upon to explain, and continues with a section on the classical theory of the electron. The quantum theory of fields is then founded on Schwinger's action principle. At this high level the interaction of the electromagnetic with the electron field is evolved as far as the discussion of divergences and renormalization. The electrodynamics of scalar particles is not treated, and references are somewhat scanty. A useful collection of problems and solutions is appended. E. CORINALDESI

ELECTRONIC THEORY OF VALENCY

An Introduction to the Electronic Theory of Valency (*third edition*), by J. C. Speakman. Pp. vii + 180. Edward Arnold (Publishers) Limited, London. 1955. 10s. 6d. net.

Those familiar with the earlier editions of Dr Speakman's lucid book on valency theory will welcome this new version, now made up to date and divided into two parts.

Part I describes, at sixth form or intermediate level, the rules, aptly called Sidgwickian, for writing simple electronic formulae. Only minor blemishes were noticed in a treatment admirably suited to its purpose: an impression that carbon monoxide is highly polar, and misleading values for the electron affinity of oxygen and the electrode potential of magnesium. The reader of Part II, assumed to be a first-year undergraduate, is introduced to most of the main ideas now current. A new chapter, excellent within the limits of pictorial description, discusses wave mechanics, including the valency bond and molecular orbital methods. Then follow such topics as bond lengths and energies, electronegativity, van der Waals' forces, the hydrogen bond, transition elements, acids and bases (including the Lewis concept), and non-stoichiometric electron-deficient and clathrate compounds.

This rather unusual combination of text at two levels within a single volume should appeal particularly to the more adventurous sixth-former. One hopes, however, that the university freshman will also encounter a more rigorous treatment of some portion of this very wide field.

K. W. SYKES

ELEMENTARY CHEMISTRY

College Chemistry (*second edition*), by Linus Pauling. Pp. xii + 685. W. H. Freeman and Company, California; Bailey Bros and Swinfen Limited, London. 1955. 51s. net.

For the second edition of this book, which has had a considerable and well deserved success in the United States and is widely known in Britain, various changes in the sequence of the chapters have been made, and there is an entirely new chapter on the electron and the nuclei of atoms. Some new illustrative exercises are given in the text, and the exercises at the ends of the chapters have been considerably revised, with elimination of some of the more difficult ones. More attention is paid to organic chemistry, and there is a chapter on biochemistry. In general, the revision has been on lines intended not merely to bring the book up to date, but to introduce the facts, concepts, and theories of chemistry more gradually and more systematically than in the first edition.

For those not already familiar with the book, it may be said that it forms an excellent introduction to chemistry at first-year undergraduate stage and a most useful supplementary text for sixth-form science specialists. One has the impression that the student using it would realize that his steps were being guided by a master of his subject, and the confidence so inspired would lead to rapid progress. Besides the carefully chosen exercises there are at the end of each chapter two or three paragraphs summarizing the concepts and terms used in it, a feature enabling the reader to cross-examine himself on the extent to which he has assimilated what he has been reading. There are appendices on the metric system, physical and chemical constants, and the vapour pressure of water, together with a full index. The book is copiously illustrated with clear diagrams. As with so many American books, the price is high by British standards, but in this case the buyer would get full value for money. E. J. HOLMYARD

LAVOISIER

Lavoisier Théoricien et Expérimentateur, by Maurice Daumas. Pp. 180. Presses Universitaires de France, Paris. 1955. Fcs 700 net.

Dr Maurice Daumas, of the Conservatoire National des Arts et Métiers, Paris, is already well known for his valuable study, *Les Instruments Scienti-*

fiques aux XVII^e et XVIII^e Siècles, a work which on its first appearance in 1953 was at once welcomed as a classic of its kind. His earlier book, *Lavoisier* (1941), written for the general reader, attracted much attention and has been republished in several editions. Here he turns again to Lavoisier with an authoritative, informed, and documented survey, presenting with masterly clarity in the brief space of 180 pages the work of the founder of modern chemistry as it unfolds in its eighteenth-century setting of ideas, methods, and apparatus. There can be no chemist who would not find this presentation of the historic foundation of his science of absorbing interest, especially as the author sets aside all questions of priority and, much more usefully, gives in one chapter a most valuable chronology of Lavoisier's researches and publications. A very interesting feature of the book is the chapter in which the author gives an account of his own long and careful researches on the composition of Lavoisier's classic *Traité élémentaire de Chimie*.

D. MCKIE

CHEMICAL KINETICS

The Chemical Kinetics of Excited States, by K. J. Laidler. Pp. 180. Clarendon Press, Oxford. 1955. 30s. net.

Although in the majority of chemical reactions only the most stable electronic configurations of the participating species are involved, excited states play a crucial role in many processes, of considerable theoretical and practical interest, which occur in radiochemical or photochemical transformations and in flames. This book can be recommended to readers with some general knowledge of physical chemistry as an excellent survey of the fundamental concepts of a rather specialized branch of kinetics.

After a brief introduction on radiation and high-energy particles, the two main theoretical problems in the use of semi-empirical potential energy surfaces are discussed: the correlation of the various excited states of the transition complex with the appropriate levels of reactants and products, and the probability of transitions from one surface to another. Subsequent chapters deal with the various methods of excitation, and then with the elementary reactions of excited molecules such as dissociation, isomerization, association, and energy transfer. To illustrate the applications of these principles there are comparisons of the thermal,

photochemical, and radiochemical mechanisms of some of the classical examples in chemical kinetics, e.g. ortho-para hydrogen conversion, decomposition of hydrogen iodide, combination of hydrogen and bromine. The book concludes with a chapter on the spectroscopic approach to flames.

K. W. SYKES

DYESTUFFS CHEMISTRY

The Chemistry of Synthetic Dyes and Pigments, *edited by H. A. Lubs. Pp. xii + 734. Reinhold Publishing Corporation, New York. 1955. £7 8s. net.*

The number of authoritative books on the chemistry or the manufacture of dyes and pigments is ridiculously small, and for this reason alone a new work of the scope and magnitude of this one will be welcomed. It is published as one of the American Chemical Society's well known monographs and maintains both in content and presentation the high standard of these publications. No single person can write with authority from first-hand experience of the many classes of dyes of which industry makes use, and this book is written by a team of nineteen contributors, all of whom, including the editor, have spent their scientific lives in the Jackson Laboratory of the Du Pont Company. The writers approach their subjects from the purely chemical aspect, discussing the processes involved in the preparation of intermediates and their conversion into dyes, and the properties of the dyes in relation to the functions they are expected to perform—the research workers' approach.

Although the fourteen chapters of the book cover all the different classes of organic dyes and pigments, the space devoted to each subject reflects the importance assigned to the different classes in America, as measured by dollar value of production. Most space is given to azo and azoic dyes (130 pages, four writers) and dyes derived from anthraquinone, including related vat dyes (216 pages, five writers); indigoid dyes are given 26 pages, sulphur dyes 33 pages, and a very large miscellaneous class which includes acridine, azine, thiazine, and the important triarylmethane dyes has to be content with 70 pages. However, the subjects in which the writers are obviously interested are admirably discussed. A feature of the book is the inclusion of a great deal of information gleaned from German sources after the last war and incorporated in FIAT and

BIOS reports, information not well documented nor readily accessible. One must mention also the excellent account of the phthalocyanine pigments and dyes (no less than 50 pages). Full credit is given to British chemists for this discovery, certainly the most significant innovation in the field of synthetic dyes of the last twenty-five years.

E. H. RODD

THEORY OF INORGANIC ANALYSIS

Grundlagen der analytischen Chemie und der Chemie in wässrigen Systemen, *by F. Seel. Pp. 348. Verlag Chemie G.m.b.H., Weinheim/Bergstr. 1955. DM 29 net.*

In this book Professor Seel interprets to the first- or second-year student of inorganic analysis the theoretical background of aqueous-solution chemistry. The task is not an easy one, because it involves an introduction to selected physico-chemical problems at a stage where the student has not yet become acquainted with the basic principles of physical chemistry, but the author achieves his aim with some measure of success.

After deriving, perhaps somewhat naively, the mass-law on the concentration scale, by equating the forward and backward reactions on the basis of collision frequencies, the author introduces single-ion activities for the purpose of obtaining 'really constant' mass-law constants. Having thus avoided the complexities of thermodynamics, which might have frightened off the tender student, the author ably discusses the processes of solubility and precipitation, with the various implications deriving from crystal size and colloid formation. Equally well produced are the substantial chapters on the formation of complexes, on acid-base reactions, and on indicators. A small chapter (rather too small, considering the increasing importance of the subject in the analytical field) is devoted to ion exchange. The reader misses mention of 'mixed-bed' de-ionization, nor is there any reference to the analytically useful separations by ion exchange columns of mixtures such as Na-K, or to elution with complexing agents as in the case of Sr-Ba and rare-earth separations.

A substantial part of the book is devoted to the understanding of oxidation and reduction processes, reversible and otherwise, and the effect on them of complex formation. The various types of pH titration using indicators, redox potentials, and potentiometric

cells get a fair discussion. Extensive tables are appended giving the pK values of solubilities and complex stabilities, as well as the normal redox potentials of a large number of compounds.

The treatment of the subject as a whole is obviously not intended for the more advanced analyst, and literature references, which might have filled the gaps unavoidable in a book of this size, are completely absent. But the book is well produced and, in spite of some limitations, contains a large number of valuable facts and data. It should make a useful contribution to the working knowledge of any young student of analytical chemistry, and should be extremely valuable to scientific assistants without a university training who work in analytical laboratories and who wish to understand the implications of what they are doing.

E. GLUECKAUF

PARASITISM

Some Physiological Aspects and Consequences of Parasitism, *edited by William H. Cole. Pp. xi + 90. Rutgers University Press, New Brunswick, New Jersey. 1955. \$2 net.*

Since 1945 the Bureau of Biological Research at Rutgers University has sponsored annual conferences on some aspect of protein metabolism; in 1955 the conference took into account the important fact that parasitic organisms, even though they are not causing disease that produces clinical symptoms, may nevertheless alter the metabolic balance of the host, with the result that experimental animals considered to be normal are not, in fact, giving normal responses. The report of this conference shows that, although this problem is complex, valuable contributions have already been made to the study of it, and, indeed, to the study of the physiology of host-parasite relationships in general.

Studies of intracellular parasites are represented by William Trager's paper on the *in vitro* study of malarial parasites of birds; by Stauber's paper on leishmaniasis of the hamster; and by Moulder's discussion of the protein metabolism of bacteriophages, typhus rickettsiae, and malarial parasites. Taliaferro discusses his recent work on the formation of antisheep haemolysins in the rabbit; Bueding the glycolytic enzymes of *Schistosoma mansoni*; and Read intestinal physiology and its relation to the metabolism of tapeworms.

All these papers indicate that we stand on the threshold of research which will eventually transform our methods of dealing with parasites which still, in spite of recent remarkable advances in their control, cause heavy economic losses all over the world and incalculable human and animal suffering.

G. LAPAGE

GENETIC LETHAL FACTORS

Letalfaktoren, by E. Hadorn. Pp. 338. Georg Thieme Verlag, Stuttgart. 1955. DM 39 net.

This monograph is the first book devoted entirely to genetic lethal factors—that is to say, to genes which bring about the death of the individuals in which they are manifested. It is an important work, not so much because lethal genes differ in any profound way from others, but because they offer favourable technical opportunities for approaching two of the most fundamental topics in genetics—the nature of gene mutation and the manner in which genetic factors produce their developmental effects. Hadorn deals with both of these problems in some detail, although it is to the latter that the bulk of his book is devoted.

The particular merit of the book is its careful theoretical analysis, supported by the citation of many experimental and descriptive studies, of the complex syndromes of aberrations which a single gene may produce. Hadorn discusses in detail the evidence for the existence of particular phases of development at which the action of a given gene becomes manifest, and for cell and organ specificity in gene activity. His own recent work, in which he has used chromatographic methods to reveal the biochemical changes brought about by certain lethal genes, is fully summarized and its significance discussed. The book will be not only a most useful compendium and source of information, but by the clarity and comprehensiveness of its theoretical structure will contribute considerably to the advance of developmental genetics. C. H. WADDINGTON

COOK'S VOYAGES

The Botany of Cook's Voyages (Volume 14, Number 5/6), by E. D. Merrill. Pp. iv + 161–384. *Chronica Botanica Company*, Waltham, Mass. 1954. \$4.75 net.

The title of this work is somewhat misleading, since the author's interest is concentrated, not on the native vegetation of the areas visited during

Cook's voyages, but only upon the introduced cultivated plants and weeds.

The material collected by Banks and Solander on Cook's first voyage (1768–71), and by the two Forsters on the second voyage, provide the main evidence for the views expressed by Dr Merrill. It is held that these collections were of a comprehensive character with respect to the areas visited, and demonstrate that most of the introduced plants of the Pacific islands today were arrivals subsequent to 1769. The Spaniards and Portuguese are considered to have been the pioneers in weed distribution throughout this area, and during the two hundred and fifty years of the Galleon Line from Mexico to the Philippines they probably introduced some two hundred species. The idea that American cultivated plants and weeds were widely dispersed in pre-Magellan times is discredited. Perhaps not more than two or three weeds of American origin became established on Pacific islands until within the last two centuries.

In 1769 two hundred and sixty plant species were collected in Tahiti, of which sixty-three were probably brought by human agency. Thirty of these have an economic value and may well represent deliberate introductions; there was a similar number of weeds, but of Indo-Malaysian origin.

The text of this work would have gained both in interest and effectiveness had the author been less polemical. It is obvious that his conclusions are based on considerable research, but though indexes are provided for both plant names and for authors there is no subject index, an omission that one regrets.

E. J. SALISBURY

PHOTOSYNTHESIS

Photosynthesis, by R. Hill and C. P. Whittingham. Pp. vii + 165. Methuen and Company Limited, London. 1955. 8s. 6d. net.

The study of photosynthesis has now progressed through stages based respectively on plant anatomy, plant physiology, physical chemistry, and biochemistry, and it is the special merit of this little book that, within its narrow compass, all these stages are fairly represented. It is interesting, for example, to find an adequate account of what may now be called the classical kinetic studies of the plant physiologists which provided basic data already rather apt to be overlooked.

The presentation is, in general, lucid,

and will not overtax the abilities of the average degree student in botany or biochemistry; a few slips and ambiguities are noticeable mainly by contrast. There is some unevenness of treatment between different sections, presumably due to the dual authorship, and restricted space is doubtless the cause of some debatable statements being made *ex cathedra*. Chapter 6 contains a good deal of general biochemistry available elsewhere, and it might have been better to divert some of its pages to a description of supporting evidence, as is done in Chapter 7 but not much elsewhere.

The account of recent work is as up to date as can be expected, having regard to the delays of modern publication and the rapid progress of the subject. The authors are to be congratulated wholeheartedly on a remarkable achievement, and they have placed botany and biochemistry students heavily in their debt. W. O. JAMES

POPULAR BOTANY

La Vie des Plantes, by A. Guillaumin, F. Moreau, and C. Moreau. Pp. 468. Librairie Larousse, Paris. 1955. Fcs 6190 net.

This is the latest addition to the *Collection in quarto Larousse* and is intended particularly as a companion volume to *La Vie des Animaux* published earlier. The aims of the series, in which this is the ninth title, are to provide an inspiring introduction to the world of ideas, irreproachable documentation of the sum of modern knowledge, illustration of a quality to charm the eye and enlighten the mind, and, generally, a presentation making full use of the progress of graphic art.

Having hitched the wagon to so high a star one can only fail honourably, if at all, and the three authors have indeed attacked their subject in the grand style. It would be difficult to think of any aspect of the plant sciences to which they have not alluded, from academic morphology to topiary, or from growing mushrooms in caves to growing millet on the equator.

The illustrations can be described only as magnificent, especially those in black and white, which are exciting even to a hardened botanist. This is the ideal present for an amateur of plants. Even if he were without the smattering of French necessary for reading the text, the 1518 illustrations would give him hours of enjoyment. There is unfortunately no index.

W. O. JAMES

RATS AND MICE

Les Rongeurs Domestiques Nuisibles, by J. Lhoste. Pp. 149. Dunod, Paris. 1955. Fcs 730 net.

In this recent addition to the series *Les Heures Scientifiques* Dr Lhoste provides a most useful, authoritative, and up to date handbook on rats and mice and their control. He begins by describing the chief differences between *Rattus norvegicus*, *Rattus rattus*, and *Mus musculus*, their parasites, and the diseases they spread. There follows a short section on proofing and rubbish disposal and then some eighty pages on methods of destruction—mainly chemical—wherein will be found the most interesting part of the book for readers already familiar with rodent control problems.

If this admirable publication can be criticized on general grounds it is because here and there, and perhaps to British eyes only, it lacks balance—as for example where it devotes nine pages to rubbish disposal in France, four pages to the botany of *Urginea maritima* and the extraction of red squill, and only eight lines to arsenic trioxide.

To mention specific points, surely more research needs yet to be done before the use of emetics in rat poisons can be recommended; and it is not generally true that warfarin is tasteless. There is a certain lack of correspondence between the text and figures 42 and 43; this is reduced, but not entirely eliminated, by transposing the latter. This tends to obscure the important fact stated only in the caption to figure 43, and at the very end of the book, that prebaiting is unnecessary with anticoagulants.

There is a short bibliography but no index.

E. W. BENTLEY

EMBRYOLOGY

Embryologie, by D. Starck. Pp. xix + 688. Georg Thieme Verlag, Stuttgart. 1955. DM 78 net.

Professor Dietrich Starck's new textbook of embryology is a notable addition to the literature. It is conceived in the form of an introduction to general problems leading to a very full account of the development of man. The latter, with its descriptions of placentation, organogeny, and histogenesis is treated in the light of comparative anatomy and gives a vivid presentation of normal and teratological development. The former section is remarkable for the breadth of its treatment. The classical information about the formation of germ-cells is

accompanied by admirable sections on fertilization, gametes, the manifestation of the effects of genes in ontogeny, chromosomes, the determination of sex, and fundamental problems of the organization of the embryo by organizers and dependent differentiation. Beautifully produced and well illustrated, the book is thoroughly up to date and contains a mass of information which it would be difficult to find between two covers elsewhere.

The only criticism of the book which may be offered is that in some cases the references to literature in the text are not easy to pick out in the consolidated list at the end of the book, but this should not be held to detract from the welcome which its publication deserves. Its price is necessarily related to the substantial production which it represents, and is likely to prove beyond the reach of the ordinary student. The book should, however, be available in the libraries of all institutions where research and teaching on vertebrate embryology take place.

GAVIN DE BEER

BIRD NAVIGATION

Bird Navigation, by G. V. T. Matthews. Pp. vii + 141. Cambridge University Press, London. 1955. 12s. 6d. net.

Before the war, perhaps the biggest unsolved mystery connected with wild birds was how they found their way—their way home when experimentally released in unknown country and their way from breeding to winter quarters on their natural migrations. Since the war the problem has been largely solved, due especially to the work of G. Kramer at Wilhelmshaven and of the author of the present book while at Cambridge. The spur to the new approach was Kramer's brilliant observation that a caged starling, exhibiting migratory restlessness, tended to fly in one direction, and experiments showed that it found this direction by means of the sun's position and some form of internal clock. Later have come many carefully conducted experiments on the homing of pigeons by Kramer and Matthews. Matthews also obtained valuable, and at times spectacular, results with Manx shearwaters, one of which homed from the United States to Wales.

The present book is a well ordered and competent review of existing knowledge. It is based on the author's own research, together with many judicious and critical references to the work of others, and he presents a well reasoned

and modestly argued case for his own theory of bird navigation by means of a grid derived from the sun's arc.

Perhaps because this mystery has in the past evoked so much highly coloured writing from the nature journalist, the author has written throughout in the dry technical language of the laboratory; this is a pity, because, with greater simplicity in the telling, the tale would have fascinated many amateur bird-watchers.

DAVID LACK

PHYSIOLOGY OF DIAPAUSE

The Physiology of Diapause in Arthropods, by A. D. Lees. Pp. x + 151. Cambridge University Press, London. 1955. 12s. 6d. net.

The phenomenon of diapause, or arrested growth, has been for many years of great concern to physiologists and economic entomologists, and Dr A. D. Lees' summary and reassessment of literature on this subject is timely and welcome. There is a growing interest in this general biological problem, and more than half of the 286 papers cited have been published within the last decade.

The author points out that the term diapause is a reminder of the physiological mechanisms which are absent in the state of quiescence and assembles much recent information on a metabolic and biochemical adjustments of dormant insects and mites. Much of the book is devoted to the influence of the environment on diapause, and the section on the effect of the length of day on dormancy is particularly stimulating.

One of the most outstanding advances in the study of diapause is the discovery that it is controlled by hormones and that different endocrine systems are concerned in the embryonic, larval-pupal, and the imaginal diapause. The recent discovery that a hibernating hormone affects the rate of embryonic development, as well as the extensive work on the endocrinology of diapause of larvae and pupae, are admirably summarized. The unifying principles underlying the phenomenon of diapause are only now beginning to emerge, and the author is not to be blamed if at times the ideas expressed in this monograph are not as clearly defined as one would wish.

It seems almost ungracious to point out minor mistakes in a monograph produced at such a high standard, but it is perhaps worth noting the race of *cinerascens* of *Lucasta migratoria* is wrongly referred to as *canescens*. N. WALOFF

Some books received

(Note. Mention of a book on this page does not preclude subsequent review.)

ASTRONOMY

The Sun and its Influence, by M. A. Ellison. Pp. xii + 235. Routledge and Kegan Paul Limited, London. 1955. 21s. net.

BIOLOGY

Fibrous Proteins and their Biological Significance (Symposium of the Society for Experimental Biology, No. 9). Pp. vi + 370. Cambridge University Press, London. 1955. 50s. net.

The Luminescence of Biological Systems, edited by F. H. Johnson. Pp. xiv + 452. American Association for the Advancement of Science, Washington, D.C. 1955. \$7.

The Mechanism of Evolution, by W. H. Dowdeswell. Pp. ix + 99. William Heinemann Limited, London. 1955. 6s. net.

Problèmes de structures, d'ultrastructures et de fonctions cellulaires, edited by J. A. Thomas. Pp. 358. Masson et Cie., Paris. 1955. Fcs 3000 net.

Receptors and Sensory Perception, by R. Granit. Pp. xi + 369. Yale University Press, Newhaven; Geoffrey Cumberlege, Oxford University Press, London. 1955. 40s. net.

BOTANY

Contributions to Plant Anatomy, by I. W. Bailey. Pp. xxvi + 285. Chronica Botanica Company, Waltham, Mass. 1955. \$7.50 net.

Handbuch der Pflanzenzüchtung (second edition), Volume 1, edited by H. Kappert and W. Rudolf. Pp. 80. Verlag Paul Parey, Berlin. 1955. DM 13.50 net.

CHEMISTRY

Biochemistry of Autotrophic Bacteria, by H. Lees. Pp. viii + 112. Butterworths Scientific Publications, London. 1955. 21s. net.

The Chemistry of Petroleum Hydrocarbons, edited by B. T. Brooks, C. E. Boord, S. S. Kurtz, and L. Schmerling. Volume 2, pp. vi + 448; Volume 3, pp. vii + 690. Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London. 1955. 108s. net and 144s. net respectively.

Physical Chemistry, by F. Daniels and R. A. Alberty. Pp. vi + 671. John Wiley

and Sons Inc., New York; Chapman and Hall Limited, London. 1955. 52s. net.

The Quantitative Analysis of Drugs (second edition), by D. C. Garratt. Pp. xv + 670. Chapman and Hall Limited, London. 1955. 70s. net.

GENERAL

Directory of Scientific Research Organizations in the Union of South Africa, edited by D. Ryle Masson. Pp. ix + 123. J. L. Van Schaik Limited, Pretoria. 1955. 25s. net.

The Foreseeable Future, by Sir George Thomson. Pp. vii + 166. Cambridge University Press, London. 1955. 10s. 6d. net.

Machine Translation of Languages, edited by W. N. Locke and A. D. Booth. Pp. xii + 243. The Technology Press of The Massachusetts Institute of Technology and John Wiley and Sons Inc., New York; Chapman and Hall Limited, London. 1955. 48s. net.

The Practice of Management by P. F. Drucker. Pp. viii + 355. William Heinemann Limited, London. 1955. 25s. net.

Proceedings of the Commonwealth Oceanographic Conference, 1954. Pp. v + 92. Cambridge University Press, London. 1955. 7s. net.

Two Ears of Corn, Two Blades of Grass, by D. H. Killeffer. Pp. x + 139. D. Van Nostrand Company Inc., New York; Macmillan and Company Limited, London. 1955. 30s. net.

MEDICINE

Advances in Experimental Caries Research. Pp. ix + 236. American Association for the Advancement of Science, Washington, D.C. 1955. \$6.75.

Antimetabolites and Cancer, edited by C. P. Rhoads. Pp. vi + 312. American Association for the Advancement of Science, Washington, D.C. 1955. \$5.75.

British Medical Bulletin, Volume 11, No. 2 (Hormones in Reproduction), edited by A. S. Parkes. Pp. 83-170. The British Council, London. 1955. 15s. net.

British Pharmacopocia 1953. Addendum 1955. Pp. xvii + 94. The Pharmaceutical Press, London. 1955. 21s. net.

Experimental Tuberculosis, edited by G. E. W. Wolstenholme. Pp. xii + 396. Ciba Foundation Symposium. J. and A. Churchill Limited, London. 1955. 42s. net.

The Extra Pharmacopocia (Martindale), Volume 2 (twenty-third edition). Pp. xxxi + 1501. The Pharmaceutical Press, London. 1955. 57s. 6d. net.

Symposium on Atherosclerosis. Pp. 249. National Academy of Sciences—National Research Council, Washington, D.C. 1954. \$2 net.

PHYSICS

Boltzmann's Distribution Law, by E. A. Guggenheim. Pp. 61. North-Holland Publishing Company, Amsterdam. 1955. 5s. 6d. net.

Journal of Electronics, Volume 1, No. 1. Pp. 102. Taylor and Francis Limited, London. 1955. 20s. net.

Molecular Beams, by K. F. Smith. Pp. x + 133. John Wiley and Sons Inc., New York; Methuen and Company Limited, London. 1955. 8s. 6d. net.

Nuclear Radiation Detectors, by J. Sharpe. Pp. 179. Methuen and Company Limited, London. 1955. 11s. 6d. net.

Optique électroniques, Volume 1. Lentilles électroniques, by P. Grivet, M.-T. Bernard, and A. Septier, with a preface by Louis de Broglie. Pp. 84. Bordas, Paris. 1955. Fcs 1450 net.

Principles and Applications of Physics, by O. Blüh and J. D. Elder. Pp. xiv + 866. Oliver and Boyd Limited, London. 1955. 45s. net.

Radiocarbon Dating (second edition), by W. F. Libby. Pp. ix + 175. The University of Chicago Press, Chicago; Cambridge University Press, London. 1955. 34s. net.

ZOOLOGY

Biology of a Marine Copepod, by S. M. Marshall and A. P. Orr. Pp. vii + 188. Oliver and Boyd Limited, London. 1955. 21s. net.

Birds of Saurashtra, India, by R. S. Dharmakumarsinhji. Pp. liii + 561. R. S. Dharmakumarsinhji, Dil Bahar, Bhavnagar, Saurashtra. 1955. £5 12s. 6d. net.

A Catalogue and Historical Account of the Banks Shell Collection, by G. L. Wilkins. Pp. 69-119. British Museum (Natural History), London. 1955. 20s. net.

Notes on contributors

J. Z. YOUNG,

M.A., F.R.S.,

Was born in 1907 and was educated at Marlborough College and the University of Oxford. Specializing in zoology, he worked for two years at the Marine Biological Station at Naples, afterwards returning to Oxford, where he became Fellow of Magdalen College and University Demonstrator in Zoology. He is now Professor of Anatomy at University College, London. His research work has been on the microscopic structure and function of various tissues, especially in the nervous system. During 1936 he held a Fellowship of the Rockefeller Foundation and worked at Chicago and Woods Hole, Mass. Before the war while investigating the nervous system of squids he discovered the giant nerve fibres which have proved exceptionally suitable for experiment. During the war he conducted research on methods of treating injuries of peripheral nerves and was a member of the Nerves Injuries Committee of the Medical Research Council. Since the war he has done much work on octopuses and similar animals in an attempt to throw light on the mechanism of learning.

H. M. POWELL,

M.A., B.Sc., F.R.S.,

Was born in 1906 and was educated at King Henry VIII School, Coventry, and St. John's College, Oxford. In 1929 he was appointed Demonstrator in the former Department of Mineralogy and Crystallography, Oxford, where he began to apply X-ray crystal analysis to chemical problems. In 1944 he was appointed Reader in Chemical Crystallography, in charge of a re-organized department devoted to that subject. His crystal structure investigations deal with molecular compounds, stereochemical types, and the constitutions of organometallic compounds, phosphorus pentahalides, metal carbonyls, and ferrocyanides. His most recent investigations have been on stable molecular compounds formed by the inert gases.

H. J. J. WINTER,

*D.Sc., Ph.D., A.Inst.P.,
F.R. Asiatic S.,*

Was born in 1912 and was educated at the City School, Lincoln, University College, Nottingham, and University College, Exeter. He is a member of the History of Science Society and of the British Society for the History of Science. Lecturer in Education (Scientific Method and History of Science) in the University College of the South West, Exeter. He has published 'Eastern Science' and many papers on the history of science.

A. W. JOHNSON,

M.A., Ph.D., A.R.C.S.,

Was born in 1917 in South Shields, County Durham, and was educated at Morpeth Grammar School and, after two years in industry, at the Royal College of Science, South Kensington. After carrying out research on the synthesis of vitamin A with Sir Ian Heilbron, he took up in 1942 a research appointment with I.C.I. Dyestuffs Division, working on the chemistry of acetylene and its derivatives. In 1946 he was awarded an I.C.I. Fellowship at the University of Cambridge in Professor Sir Alexander Todd's department. In 1948 he was made Assistant Director of Research and, in 1953, University Lecturer in Organic Chemistry. His research has covered a variety of natural products, including vitamin B₁₂. In 1955 was appointed Sir Jesse Boot Professor of Organic Chemistry in the University of Nottingham. Was awarded the Meldola Medal of the Royal Institute of Chemistry in 1946, and gave the Tilden lecture of The Chemical Society in 1953.

SIR ALEXANDER TODD,

*M.A., D.Sc., Hon. LL.D., Hon. Dr.
Rev. nat., F.R.S.,*

Was born in Glasgow in 1907 and was educated at Allan Glen's School and the University of Glasgow. He con-

tinued his studies at the Universities of Frankfurt and Oxford, and in 1935-36 was Beit Memorial Research Fellow at the University of Edinburgh. After holding posts at the Lister Institute, London, the University of London, and the California Institute of Technology, he was appointed Professor of Chemistry and Director of Chemical Laboratories in the University of Manchester in 1938. Since 1944 he has been Professor of Organic Chemistry in the University of Cambridge. He is a Davy Medallist (1949) and Royal Medallist (1955) of the Royal Society, and since 1952 has been chairman of the Advisory Council on Scientific Policy. He has always been keenly interested in the biological side of organic chemistry, to which he has made numerous and important original contributions.

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